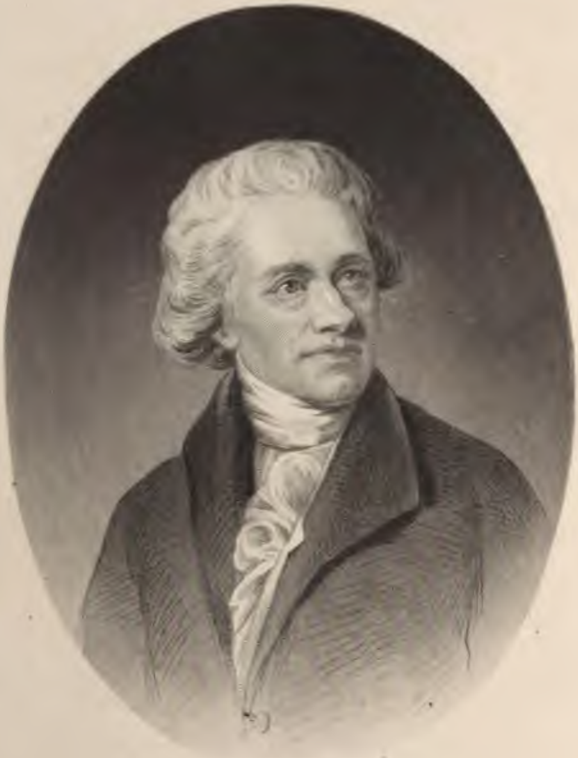
SIR WILLIAM HERSCHEL

HIS LIFE AND WORKS



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EDWARD S. HOLDEN
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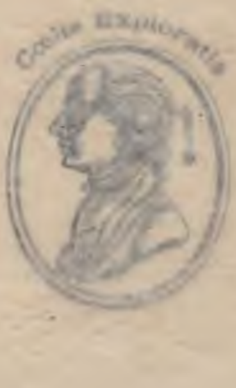

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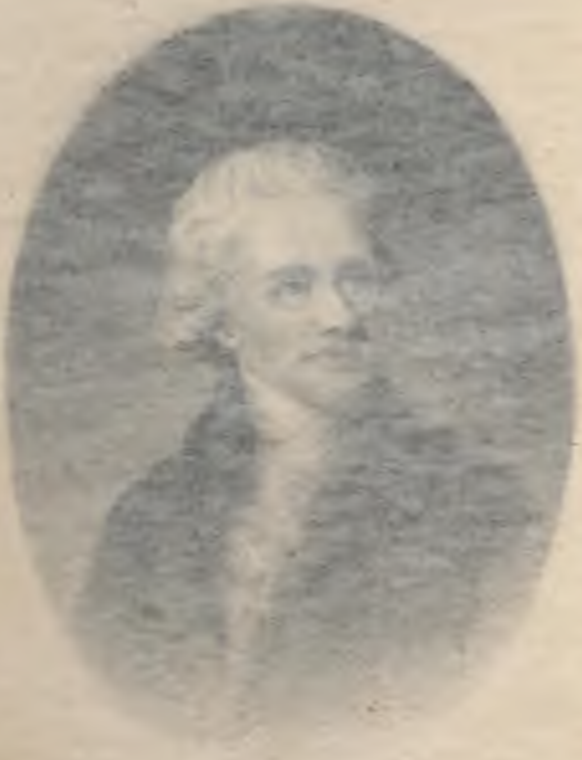

SIR WILLIAM HERSCHEL

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BY

EDWARD S. HOLDEN

UNITED STATES NAVAL OBSERVATORY, WASHINGTON

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PREFACE.

In the following account of the life and works of Sir William Herschel, I have been obliged to depend strictly upon data already in print—the *Memoir* of his sister, his own scientific writings and the memoirs and diaries of his cotemporaries. The review of his published works will, I trust, be of use. It is based upon a careful study of all his papers in the *Philosophical Transactions* and elsewhere.

A life of Herschel which shall be satisfactory in every particular can only be written after a full examination of the materials which are preserved at the family seat in England; but as two generations have passed since his death, and as no biography yet exists which approaches to completeness, no apology seems to me to be needed for a conscientious attempt to make the best use of the scanty material which we do possess.

This study will, I trust, serve to exhibit so much of his life as belongs to the whole public. His private life belongs to his family, until the time is come to let the world know more of the greatest of practical astronomers and of the inner life of one of its most profound philosophers,—of a great and ardent mind, whose achievements are and will remain the glory of England.

CONTENTS.

LIFE AND WORKS

OF

WILLIAM HERSCHEL.

CHAPTER I.

EARLY YEARS; 1738–1772.

OF the great modern philosophers, that one of whom least is known, is WILLIAM HERSCHEL. We may appropriate the words which escaped him when the barren region of the sky near the body of *Scorpio* was passing slowly through the field of his great reflector, during one of his sweeps, to express our own sense of absence of light and knowledge: *Hier ist wahrhaftig ein Loch im Himmel.*

HERSCHEL prepared, about the year 1818, a biographical memorandum, which his sister CAROLINA placed among his papers.

This has never been made public. The only thoroughly authentic sources of information in possession of the world, are a letter written by HERSCHEL himself, in answer to a pressing request for a sketch of his life, and the *Memoir and Correspondence of* CAROLINE HERSCHEL (London, 1876), a precious memorial not only of his life, but of one which otherwise would have remained almost unknown, and one, too, which the world could ill afford to lose. The latter, which has been ably edited by Mrs. MARY CORNWALLIS HERSCHEL,* is the only source of knowledge in regard to the early years of the great astronomer, and together with the all too scanty materials to be gained from a diligent search through the biography of the time, affords the data for those personal details of his life, habits, and character, which seem to complete the distinct, though partial conception

* Wife of Major JOHN HERSCHEL, of the Royal Engineers, grandson of Sir WILLIAM.

of him which the student of his philosophical writings acquires.

The letter referred to was published in the Göttingen Magazine of Science and Literature, III., 4, shortly after the name of HERSCHEL had become familiar to every ear through his discovery of *Uranus*, but while the circumstances of the discovery, and the condition of the amateur who made it, were still entirely unknown.

The editor (LICHTENBERG) says:

"Herr HERSCHEL was good enough to send me, some time since, through Herr MAGELLAN, copies of his Dissertations on Double Stars, on the Parallax of the Fixed Stars, and on a new Micrometer. In the letter which conveyed to him my thanks for his gift, I requested him to note down a few facts in regard to his life, for publication in this magazine, since various accounts, more or less incorrect, had appeared in several journals. In answer, I received a very obliging letter from him, and what follows is that portion of it relating to my request, which was sent me with full permission to make it public."

"DATCHET, NEAR WINDSOR,
Nov. 15, 1783.

"I was born in Hanover, November, 1738. My father, who was a musician, destined me to the same profession, hence I was instructed betimes in his art. That I might acquire a perfect knowledge of the theory as well as of the practice of music, I was set at an early age to study mathematics in all its branches—algebra, conic sections, infinitesimal analysis, and the rest.

"The insatiable desire for knowledge thus awakened resulted next in a course of languages; I learned French, English, and Latin, and steadfastly resolved henceforth to devote myself wholly to those sciences from the pursuit of which I alone looked for all my future happiness and enjoyment. I have never been either necessitated or disposed to alter this resolve. My father, whose means were limited, and who consequently could not be as liberal to his children as he would have desired, was compelled to dispose of them in one way or another at an early age; consequently in my fifteenth year I enlisted in military service, only remaining in the army, however, until I reached my nineteenth year, when I resigned and went over to England.

"My familiarity with the organ, which I had carefully mastered previously, soon procured for me the position of organist in Yorkshire, which I finally exchanged for a similar situation at Bath in 1766, and while here the peculiar circumstances of my post, as agreeable as it was lucrative, made it possible for me to occupy myself once more with my studies, especially with mathematics. When, in the course of time, I took up astronomy, I determined to accept nothing on faith, but to see with my own eyes everything which others had seen before me.

Having already some knowledge of the science of optics, I resolved to manufacture my own telescopes, and after many continuous, determined trials, I finally succeeded in completing a so-called Newtonian instrument, seven feet in length. From this I advanced to one of ten feet, and at last to one of twenty, for I had fully made up my mind to carry on the improvement of my telescopes as far as it could possibly be done. When I had carefully and thoroughly perfected the great instrument in all its parts, I made systematic use of it in my observations of the heavens, first forming a determination never to pass by any, the smallest, portion of them without due investigation. This habit, persisted in, led to the discovery of the new planet (*Georgium Sidus*). This was by no means the result of chance, but a simple consequence of the position of the planet on that particular evening, since it occupied precisely that spot in the heavens which came in the order of the minute observations that I had previously mapped out for myself. Had I not seen it just when I did, I must inevitably have come upon it soon after, since my telescope was so perfect that I was able to distinguish it from a fixed star in the first minute of observation.

"Now to bring this sketch to a close. As the king had expressed a desire to see my telescope, I took it by his command to Greenwich, where it was compared with the instruments of my excellent friend, Dr. MASKELYNE, not only by himself, but by other experts, who pronounced it as their opinion that my instrument was superior to all the rest. Thereupon the king ordered that the instrument be brought to Windsor, and since it there met with marked approval, his majesty graciously awarded me a yearly pension, that I might be enabled to relinquish my profession of music, and devote my whole time to astronomy and the improvement of the telescope. Gratitude, as well as other considerations specified by me in a paper presented to the Royal Society, of which I am a member, has induced me to call the new planet *Georgium Sidus.*

"'Georgium Sidus.—jam nunc assuesce vocari.'—(*Virgil.*)

And I hope it will retain the name."

We know but little of the family of HERSCHEL. The name is undoubtedly Jewish. and is found in Poland, Germany, and England. We learn that the ancestors of the present branch left Moravia about the beginning of the XVIIth century, on account of their change of religion to Protestantism. They became possessors of land in Saxony. HANS HERSCHEL, the great-grandfather of WILLIAM, was a brewer in Pirna (a small town near Dresden). Of the two sons of HANS, one, ABRAHAM (born in 1651, died

1718), was employed in the royal gardens at Dresden, and seems to have been a man of taste and skill in his calling. Of his eldest son, EUSEBIUS, there appears to be little trace in the records of the family. The second son, BENJAMIN, died in infancy; the third, ISAAC, was born in 1707 (Jan. 14), and was thus an orphan at eleven years of age. ISAAC was the father of the great astronomer.

He appears to have early had a passionate fondness for music, and this, added to a distaste for his father's calling, determined his career. He was taught music by an oboe-player in the royal band, and he also learned the violin. At the age of twenty-one he studied music for a year under the Cappelmeister PABRICH, at Potsdam, and in August, 1731, he became oboist in the band of the Guards, at Hanover. In August, 1732, he married ANNA ILSE MORITZEN. She appears to have been a careful and busy wife and mother, possessed of no special faculties which would lead us to attribute to her care any great part of the abilities of her son.

She could not herself write the letters which she sent to her husband during his absences with his regiment. It was her firm belief that the separations and some of the sorrows of the family came from too much learning; and while she could not hinder the education of the sons of the family, she prevented their sisters from learning French and dancing. It is but just to say that the useful accomplishments of cooking, sewing, and the care of a household, were thoroughly taught by her to her two daughters. The father, ISAAC, appears to have been of a different mould, and to him, no doubt, the chief intellectual characteristics of the family are due. His position obliged him to be often absent from Hanover, with his regiment, but his hand appears to have been always present, smoothing over difficulties, and encouraging his sons to such learning and improvement as was to be had.

His health was seriously injured by the exposures of the campaigns, and he was left, after the Seven Years' War, with a broken constitution.

After his final return home, in 1760, his daughter gives this record of him—

"Copying music employed every vacant moment, even sometimes throughout half the night. . . . With my brother [DIETRICH]—now a little engaging creature of between four and five years old—he was very much pleased, and [on the first evening of his arrival at home] before he went to rest, the Adempken (a little violin) was taken from the shelf and newly strung, and the daily lessons immediately commenced. . . . I do not recollect that he ever desired any other society than what he had opportunities of enjoying in many of the parties where he was introduced by his profession, though far from being of a morose disposition ; he would frequently encourage my mother in keeping up a social intercourse among a few acquaintances, whilst his afternoon hours generally were taken up in giving lessons to some scholars at home, who gladly saved him the troublesome exertion of walking. . . . He also found great pleasure in seeing DIETRICH's improvement, who, young as he was, and of the most lively temper imaginable, was always ready to receive his lessons, leaving his little companions with the greatest cheerfulness to go to his father, who was so pleased with his performances that he made him play a solo on the Adempken in RAKE's concert, being placed on a table before a crowded company, for which he was very much applauded and caressed, particularly by an English lady, who put a gold coin in his little pocket.

"It was not long before my father had as many scholars as he could find time to attend. And when they assembled at my father's to make little concerts, I was frequently called to join the second violin in an overture, for my father found pleasure in giving me sometimes a lesson before the instruments were laid by, after practising with DIETRICH, for I never was missing at those hours, sitting in a corner with my knitting and listening all the while."

Here, as in all her writing, CAROLINA is simple, true, direct to awkwardness, and unconsciously pathetic even in joy.

The family of ISAAC and ANNA HERSCHEL consisted of ten children. Six of these lived to adult age. They were:

1. SOPHIA ELIZABETH; born 1733, married GRIESBACH, a musician in the Guard, by whom she had children. Five of her sons were afterwards musicians at the court, in England, where they obtained places through the influence of WILLIAM.

2. HENRY ANTON JACOB; born 1734, November 20.

4. FREDERIC WILLIAM (the astronomer); born 1738, November 15.

6. John Alexander; born 1745, November 13.

8. Carolina Lucretia; born 1750, March 16.

10. Dietrich; born 1755, September 13.

Of this family group, the important figures to us are William, Alexander, and Carolina.

Jacob was organist at the Garrison Church of Hanover in 1753, a member of the Guards' band in 1755, and first violin in the Hanover Court Orchestra in 1759. Afterwards he joined his brother William in Bath, but again returned to Hanover. In 1771 he published in Amsterdam his Opus I., a set of six quartettes, and later, in London, he published two symphonies and six trios. He appears to have been a clever musician, and his letters to his younger brother William are full of discussion on points of musical composition, etc. He died in 1792.

Dietrich, the youngest brother, shared in the musical abilities of his family, and when only fifteen years old was so far advanced as to be able to supply his brother Jacob's place in the Court Orchestra, and to give his lessons to private pupils. There is no one of the family, except the eldest daughter, whom we do not know to have possessed marked ability in music, and this taste descended truly for four generations. In the letters of Chevalier BUNSEN,* he describes meeting, in 1847, the eldest granddaughter of WILLIAM HERSCHEL, who, he says, "is a musical genius."

Three members of the family, WILLIAM, ALEXANDER, and CAROLINA, formed a group which was inseparable for many years, and while the progress of the lives of ALEXANDER and CAROLINA was determined by the energy and efforts of WILLIAM, these two lent him an aid without which his career would have been strangely different. It is necessary to understand a little better the early life of all three.

The sons of the HERSCHEL family all attended the garrison school in Hanover until they were about fourteen years old. They were taught the ordinary rudiments of knowledge—to read, to write, to cipher—and a

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* Page 127.

knowledge of French and English was added. WILLIAM especially distinguished himself in his studies, learning French very rapidly, and studying Latin and arithmetic with his master out of hours. The household life seems to have been active, harmonious, and intelligent, especially during the presence of the father, who took a great delight in the rapid progress of all his sons in music, and who encouraged them with his companionship in their studies and in their reading on all intellectual subjects.

From the *Memoir* of CAROLINA, on which we must depend for our knowledge of this early life, we take the following paragraph:

"My brothers were often introduced as solo performers and assistants in the orchestra of the court, and I remember that I was frequently prevented from going to sleep by the lively criticism on music on coming from a concert, or by conversations on philosophical subjects, which lasted frequently till morning, in which my father was a lively partaker and assistant of my brother WILLIAM, by contriving self-made instruments. . . . Often I would keep myself awake that I might listen to their animating remarks, for it made *me so happy* to see *them so happy*. But generally their conversation would branch out on philosophical subjects, when my brother WILLIAM and my father often argued with such warmth that my mother's interference became necessary, when the names LEIBNITZ, NEWTON, and EULER sounded rather too loud for the repose of her little ones, who ought to be in school by seven in the morning. But it seems that on the brothers retiring to their own room, where they shared the same bed, my brother WILLIAM had still a great deal to say ; and frequently it happened that when he stopped for an assent or reply, he found his hearer was gone to sleep, and I suppose it was not till then that he bethought himself to do the same.

"The recollection of these happy scenes confirms me in the belief, that had my brother WILLIAM not then been interrupted in his philosophical pursuits, we should have had much earlier proofs of his inventive genius. My father was a great admirer of astronomy, and had some knowledge of that science ; for I remember his taking me, on a clear frosty night, into the street, to make me acquainted with several of the most beautiful constellations, after we had been gazing at a comet which was then visible. And I well remember with what delight he used to assist my brother WILLIAM in his various contrivances in the pursuit of his philosophical studies, among which was a neatly turned 4-inch globe, upon which the equator and ecliptic were engraved by my brother."

The mechanical genius was not confined

to WILLIAM, for we read that ALEXANDER used often to "sit by us and amuse us and himself by making all sorts of things out of pasteboard, or contriving how to make a twelve-hour cuckoo clock go a week." This ability of ALEXANDER'S was turned later to the best account when he became his brother WILLIAM'S right hand in the manufacture of reflectors, eye-pieces, and stands in England. His abilities were great, and a purpose which might otherwise have been lacking was supplied through the younger brother's ardor in all that he undertook.

His musical talent was remarkable; he played "divinely" on the violoncello. He returned to Hanover in 1816, where he lived in comfortable independence, through the never-failing generosity of his brother, until his death in 1821. A notice of him in a Bristol paper says: "Died, March 15, 1821, at Hanover, ALEXANDER HERSCHEL, Esqr., well known to the public of Bath and Bristol as a performer and elegant musician; and who for forty-seven years was the admiration of the frequenters of concerts and theatres of both those cities as principal violoncello. To the extraordinary merits of Mr. HERSCHEL was united considerable acquirement in the superior branches of mechanics and philosophy, and his affinity to his brother, Sir WILLIAM HERSCHEL, was not less in science than in blood."

We shall learn more of the sister, CAROLINA, as time goes on. Now in these early years she was a silent and persistent child, growing up with a feeling that she was uncared for and neglected, and lavishing all her childish affection, as she did all that of her womanly life, on her brother WILLIAM. Throughout her long life, "my brother" was WILLIAM, "my nephew" *his* son.

The brothers JACOB and WILLIAM were, with their father, members of the band of the Guards in 1755, when the regiment was ordered to England, and they were absent from Hanover a year.

WILLIAM (then seventeen years old) went as oboist, and out of his scanty pay brought back to Hanover, in 1756, only one memento of his stay—a copy of LOCKE *On the Human Understanding*.

He appears to have served with the Guard during part of the campaign of 1757. His health was then delicate, and his parents "determined to remove him from the service—a step attended by no small difficulties." *

This "removal" was hurriedly and safely effected, so hurriedly that the copy of LOCKE was not put in the parcels sent after him to Hamburg by his mother; "she, dear woman, knew no other wants than good linen and clothing."

Thus, at last, the young WILLIAM HERSCHEL, the son of an oboe-player in the King's Guard, is launched in life for himself, in the year 1757, at the age of nineteen.

All his equipment is the "good linen and clothing," a knowledge of French, Latin, and English, some skill in playing the violin, the organ, and the oboe, and an "uncommon precipitancy" in doing what there is to be done.

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* *Memoir* of CAROLINA HERSCHEL, p. 10. Sir GEORGE AIRY, Astronomer Royal, relates in the *Academy* that this "removal" was a desertion, as he was told by the Duke of Sussex that on the first visit of HERSCHEL to the king, after the discovery of the *Georgium Sidus*, the pardon of HERSCHEL was handed to him by the king himself, written out in due form.

A slender outfit truly; but we are not to overlook what he said of himself on another occasion. "I have, nevertheless, several resources in view, and do not despair of succeeding pretty well in the end."

From 1757 to 1760—three years—we know nothing of his life. We can imagine what it was. His previous visit to England had given him a good knowledge of the language, and perhaps a few uninfluential acquaintances. On his return he would naturally seek these out, and, by means of his music, he could gain a livelihood. We first hear of him as charged with the organization of the music of a corps of the militia of Durham, under the auspices of the EARL OF DARLINGTON. "La manière dont il remplit cette mission, le fit connaître avantageusement."* The nature of the service of these militia corps, which were then forming all over England, is well described in the Autobiography of GIBBON. Every county-gentleman felt constrained to serve his country,

* FÉTIS; *Biographie universelle des musiciens*, tome V. (1839) p. 141.

and the regimental mess-rooms were filled with men of rank and fashion.

In 1760 we hear of him again. He has attracted the notice of those about him.

"About the year 1760, as MILLER* was dining at Pontefract with the officers of the Durham militia, one of them, knowing his love of music, told him they had a young German in their band as a performer on the hautboy, who had only been a few months in England, and yet spoke English almost as well as a native, and who was also an excellent performer on the violin; the officer added that if MILLER would come into another room, this German should entertain him with a solo. The invitation was gladly accepted, and MILLER heard a solo of GIARDINI's executed in a manner that surprised him. He afterwards took an opportunity of having some private conversation with the young musician, and asked him whether he had engaged himself for any long period to the Durham militia. The answer was, 'Only from month to month.' 'Leave them, then,' said the organist, 'and come and live with me. I am a single man, and think we shall be happy together; and, doubtless, your merit will soon entitle you to a more eligible situation.' The offer was accepted as frankly as it was made, and the reader may imagine with what satisfaction Dr. MIL-

* Dr. MILLER, a noted organist, and afterwards historian of Doncaster.

LER must have remembered this act of generous feeling when he hears that this young German was HERSCHEL, the Astronomer. 'My humble mansion,' says MILLER, 'consisted, at that time, but of two rooms. However, poor as I was, my cottage contained a library of well-chosen books; and it must appear singular that a foreigner who had been so short a time in England should understand even the peculiarities of the language so well as to fix upon SWIFT for his favorite author.'

"He took an early opportunity of introducing his new friend at Mr. CROPLEY'S concerts; the first violin was resigned to him; 'and never,' says the organist, 'had I heard the concertos of CORELLI, GEMINIANI, and AVISON, or the overtures of HANDEL performed more chastely, or more according to the original intention of the composers, than by Mr. HERSCHEL. I soon lost my companion; his fame was presently spread abroad; he had the offer of pupils, and was solicited to lead the public concerts both at Wakefield and Halifax. A new organ for the parish church of Halifax was built about this time, and HERSCHEL was one of the seven candidates for the organist's place. They drew lots how they were to perform in succession. HERSCHEL drew the third, the second fell to Dr. WAINWRIGHT of Manchester, whose finger was so rapid that old SNETZLER, the organ-builder, ran about the church exclaiming: *'Te tevel! te tevel! he run over te keys like one cat; he will not give my piphes room for to shpeak.'* 'During Mr. WAINWRIGHT'S performance,' says MILLER, 'I was standing in the middle aisle with HERSCHEL. 'What chance have you,' said I, 'to follow this man?' He replied, 'I don't know; I am sure fingers will not do.' On which he ascended the organ loft, and produced from the organ so uncommon a fulness, such a volume of slow, solemn harmony, that I could by no means account for the effect. After this short *ex tempore* effusion, he finished with the Old Hundredth psalm-tune, which he played better than his opponent.

"'*Ay, ay,*' cried old SNETZLER, '*tish is very goot, very goot indeet; I vil luf tish man, for he gives my piphes room for to shpeak.*' Having afterwards asked Mr. HERSCHEL by what means, in the beginning of his performance, he produced so uncommon an effect, he replied, 'I told you fingers would not do!' and producing two pieces of lead from his waistcoat pocket, 'one of these,' said he, 'I placed on the lowest key of the organ, and the other upon the octave above; thus by accommodating the harmony, I produced the effect of four hands, instead of two.'"*

The dates in this extract are not so well defined as might be wished. HERSCHEL had certainly been more than a few months in England at the time of his meeting with Dr. MILLER, which was probably about 1760. The appointment as organist at Halifax was

* *The Doctor;* by ROBERT SOUTHEY, edition of 1848, p. 140.

in 1765, and the pupils and public concerts must have filled up the intervening five years. During a part of this time he lived in Leeds, with the family of Mr. BULMAN, whom he afterwards provided with a place as clerk to the Octagon Chapel, in his usual generous manner.

All during his life he was placing some of the less fortunate and energetic members of his family.

We cannot be too grateful to Dr. MILLER, who, seeing his opportunity, used it. Their frank friendship does honor to both. HERSCHEL'S organ-playing, which no doubt had been begun when his brother was the organist of the garrison chapel at Hanover, must have been perfected at this time, and it was through his organ-playing that he was able to leave the needy life in Yorkshire.

He was sure to have emerged sooner or later, but every year spared to him as a struggling musician was a year saved to Astronomy.

During all this period, a constant correspondence was maintained between the family at Hanover and the absent son.

Many of WILLIAM's letters were written in English, and addressed to his brother JACOB, and treated of such subjects as the Theory of Music, in which he was already far advanced.

His little sister was still faithful to the memory of her *dearest* brother, and his father, whose health was steadily declining, became painfully eager for his return. In 1764 (April 2), he returned to Hanover on a very brief visit. He was attached to England, he was prospering there, and he had no inclination towards returning to a life in Hanover. His sister says:

"Of the joys and pleasures which all felt at this long-wished-for meeting with my—let me say my *dearest*—brother, but a small portion could fall to my share; for with my constant attendance at church and school, besides the time I was employed in doing the drudgery of the scullery, it was but seldom I could make one in the group when the family were assembled together.

"In the first week, some of the orchestra were invited to a concert, at which some of my brother WILLIAM's compositions, overtures, etc., and some of my eldest brother JACOB's were performed, to the great delight of my dear father, who hoped and expected that they would be turned to some profit by publishing them, but there was no printer who bid high enough.

"Sunday, the 8th, was the—to me—eventful day of my confirmation, and I left home not a little proud and encouraged by my dear brother WILLIAM's approbation of my appearance in my new gown."

The engagement of HERSCHEL at Halifax did not long continue. In 1766 he obtained an advantageous engagement as oboist at Bath, and soon after the position of organist at the Octagon Chapel was offered to him and accepted. This was a great and important change.

Bath was then, as now, one of the most beautiful cities in England, and the resort of the fashion and rank of the kingdom, who came to take the waters. It is beautifully situated on both sides of the Avon, and has many fine walks and public buildings. The aspect of the city is markedly cheerful and brilliant, owing to the nature of the white stone of which the principal houses are built, and to the exquisite amphitheatre of hills in which they lie.

The society was then gay and polite, and HERSCHEL was at once thrown into a far more intelligent atmosphere than that he had just left in Yorkshire. It was easy to get new books, to see new faces, to hear new things. The Assembly Rooms (built in 1771) were noted for their size and elegance; the theatre was the best out of London.

His position as organist of the fashionable chapel placed him in the current. His charming and engaging manners made him friends. His talents brought him admirers and pupils, and pupils brought him money.*

He began in 1766 a life of unceasing activity, which continued. In 1768 he published in London a symphony (in C) for two violins, viola, bass, two oboes, and two horns, and in the same year two military concertos for two oboes, two horns, two trumpets, and two bassoons.† He wrote pieces for the

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* He frequently gave thirty-five and thirty-eight lessons a week to pupils at this time.

† According to FÉTIS. A search for these in London has led me to the belief that FÉTIS, who is usually very accurate, is here mistaken, and that these writings are by JACOB HERSCHEL.

harp, glees, "catches," and other songs for the voice. One of these, the *Echo Catch*, was published and had even considerable vogue.

A competent musical critic writes to me of this work: "The counterpoint is clear and flowing, and is managed with considerable taste and effect. It would be difficult to explain the great cleverness shown in the construction of this *Catch* without diagrams to illustrate the movements of the parts. It is certainly an ingenious bit of musical writing."

When he left Bath (in 1782), many of these musical writings were lost, in his great haste to take up his new profession. One, specially, his sister remembers to have written out for the printer, "but he could not find a moment to send it off, nor to answer the printer's letters." This was a four-part song, "In thee I bear so dear a part." He wrote very many anthems, chants, and psalm-tunes for the excellent cathedral choir of the Octagon Chapel. Unfortunately, most of this music is not now to be found.

A notice of HERSCHEL'S life which appeared in the *European Magazine* for 1785, January, gives a very lively picture of his life at this time, and it is especially valuable as showing how he appeared to his cotemporaries.

"Although Mr. HERSCHEL loved music to an excess, and made a considerable progress in it, he yet determined with a sort of enthusiasm to devote every moment he could spare from business to the pursuit of knowledge, which he regarded as the sovereign good, and in which he resolved to place all his views of future happiness in life." . . .

"His situation at the Octagon Chapel proved a very profitable one, as he soon fell into all the public business of the concerts, the Rooms, the Theatre, and the oratorios, besides many scholars and private concerts. This great run of business, instead of lessening his propensity to study, increased it, so that many times, after a fatiguing day of fourteen or sixteen hours spent in his vocation, he would retire at night with the greatest avidity to *unbend the mind*, if it may be so called, with a few propositions in MACLAURIN's *Fluxions*, or other books of that sort."

It was in these years that he mastered Italian and made some progress in Greek.

"We may hazard a natural conjecture respecting the course of HERSCHEL's early studies. Music conducted him to mathematics, or, in other words, impelled him to study SMITH's *Harmonics*. Now this ROBERT SMITH was the author of *A Complete System of Optics*, a masterly work, which, notwithstanding the rapid growth of that branch of the science, is not yet wholly superseded. It seems to us not unlikely that HERSCHEL, studying the *Harmonics*, conceived a reverence for the author, who was at that time still living, so that from the *Philosophy of Music* he passed to the *Optics*, a work on which SMITH's great reputation chiefly rested; and thus undesignedly prepared himself for the career on which he was shortly about to enter with so much glory." *

There is no doubt that this conjecture is a true one. The *Optics* of Dr. SMITH is one of the very few books quoted by HERSCHEL throughout his writings, and there is every evidence of his complete familiarity with its conclusions and methods; and this familiarity is of the kind which a student acquires with his early text-books. One other work he quotes in the same way, LALANDE's *Astronomy*, and this too must have been deeply studied.

During the years 1765–1772, while HERSCHEL was following his profession and his

* *Foreign Quarterly Review*, volume 31.

studies at Bath, the family life at Hanover went on in much the same way.

In 1765 his father ISAAC had a stroke of paralysis, which ended his violin-playing forever, and forced him to depend entirely upon pupils and copying of music for a livelihood. He died on March 22, 1767, leaving behind him a good name, and living in the affectionate remembrance of his children and of all who knew him.

CAROLINA had now lost her best friend, and transferred to her brother WILLIAM the affection she had before divided between him and her father.

"My father wished to give me something like a polished education, but my mother was particularly determined that it should be a rough, but at the same time a useful one ; and nothing farther she thought was necessary but to send me two or three months to a sempstress to be taught to make household linen. . . . My mother would not consent to my being taught French, and my brother Dietrich was even denied a dancing-master, because she would not permit my learning along with him, though the entrance had been paid for us both ; so all my father could do for me was to indulge me (and please himself) sometimes with a short lesson on the violin, when my mother was either in good humor or out of the way. Though I have often felt myself exceedingly at a loss for the want of those few accomplishments of which I was thus, by an erroneous though well-meant opinion of my mother, deprived, I could not help thinking but that she had cause for wishing me not to know more than was necessary for being useful in the family; for it was her certain belief that my brother WILLIAM would have returned to his country, and my eldest brother not have looked so high, if they had had a little less learning.

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"But sometimes I found it scarcely possible to get through with the work required, and felt very unhappy that no time at all was left for improving myself in music or fancy work, in which I had an opportunity of receiving some instruction from an ingenious young woman whose parents lived in the same house with us. But the time wanted for spending a few hours together could only be obtained by our meeting at daybreak, because by the time of the family's rising at seven, I was obliged to be at my daily business. Though I had neither time nor means for producing anything immediately either for show or use, I was content with keeping samples of all possible patterns in needlework, beads, bugles, horsehair, etc., for I could not help feeling troubled sometimes about my future destiny; yet I could not bear the idea of being turned into an Abigail or housemaid, and thought that with the above and such like acquirements, with a little notion of music, I might obtain a place as governess in some family where the want of a knowledge of French would be no objection."

A change was soon to come in her life too; her brother William wrote to propose that she should join him at Bath—

. . . "to make the trial, if, by his instruction, I might not become a useful singer for his winter concerts and oratorios; he advised my brother Jacob to give me some lessons by way of beginning; but that if, after a trial of two years, we should not find it answer our expectation, he would bring me back again. This at first seemed to be agreeable to all parties, but by the time I had set my heart upon this change in my situation, Jacob began to turn the whole scheme into ridicule, and, of course, he never heard the sound of my voice except in speaking, and yet I was left in the harassing uncertainty whether I was to go or not. I resolved at last to prepare, as far as lay in my power, for both cases, by taking, in the first place, every opportunity, when all were from home, to imitate, with a gag between my teeth, the solo parts of concertos, *shake and all*, such as I had heard them play on the violin; in consequence I had gained a tolerable execution before I knew how to sing. I next began to knit ruffles, which were intended for my brother William, in case I remained at home—else they were to be Jacob's. For my mother and brother D. I knitted as many cotton stockings as would last two years at least."

In August, 1772, her brother arrived at Hanover, to take her back to England with him. The journey to London was made between August 16th and 26th, and soon after they went together to HERSCHEL'S house, No. 7 New King's Street, Bath.

CHAPTER II.

LIFE IN BATH; 1772–1782.

IT was to a busy life in Bath that HERSCHEL took his sister CAROLINA, then twenty-two years old. She was a perfectly untried girl, of very small accomplishments and outwardly with but little to attract. The basis of her character was the possibility of an unchanging devotion to one object; for the best years of her life this object was the happiness and success of her brother WILLIAM, whom she profoundly loved. Her love was headstrong and full of a kind of obstinate pride, which refused to see anything but the view she had adopted. As long as her life continued to be with her dearest brother, all was well with her. She had a noble aim, and her heart was more than full.

Later on, this very singleness of character brought her other years of wretchedness. It is necessary to understand the almost spaniel-like allegiance she gave, in order to comprehend the value which her services were to HERSCHEL. She supplied him with an aid which was utterly loyal, entire, and devoted. Her obedience was unquestioning, her reverence amounted almost to adoration. In their relation, he gave everything in the way of incentive and initiative, and she returned her entire effort loyally.

At first her business was to gain a knowledge of the language, and to perfect herself in singing, so that she might become a soloist in the concerts and oratorios which he was constantly giving.

In the beginning it was not easy.

. . . "As the season for the arrival of visitors to the baths does not begin till October, my brother had leisure to try my capacity for becoming a useful singer for his concerts and oratorios, and being very well satisfied with my voice, I had two or three lessons every day, and the hours which were not spent at the harpsichord, were employed in putting me in the way of managing the family.

. . . On the second morning, on meeting my brother at breakfast, he began immediately to give me a lesson in English and arithmetic, and showed me the way of booking and keeping accounts of cash received and laid out. . . . By way of relaxation we talked of astronomy and the bright constellations with which I had made acquaintance during the fine nights we spent on the postwagen travelling through Holland.

"My brother ALEXANDER, who had been some time in England, boarded and lodged with his elder brother, and, with myself, occupied the attic. The first floor, which was furnished in the newest and most handsome style, my brother kept for himself. The front room, containing the harpsichord, was always in order to receive his musical friends and scholars at little private concerts or rehearsals. . . . Sundays I received a sum for the weekly expenses, of which my housekeeping book (written in English) showed the amount laid out, and my purse the remaining cash. One of the principal things required was to market, and about six weeks after coming to England I was sent alone among fishwomen, butchers, basket-women, etc., and I brought home whatever in my fright I could pick up. . . . My brother ALEX., who was now returned from his summer engagement, used to watch me at a distance, unknown to me, till he saw me safe on my way home. But all attempts to introduce any order in our little household proved vain, owing to the servant my brother then had. And what still further increased my difficulty was, that my brother's time was entirely taken up with business, so that I only saw him at meals. Breakfast was at seven o'clock or before—much too early for me, who would rather have remained up all night than be obliged to rise at so early an hour. . . .

"The three winter months passed on very heavily. I had to struggle against *heimwehe* (home sickness) and low spirits, and to answer my sister's melancholy letters on the death of her husband, by which she became a widow with six children. I knew too little English to derive any consolation from the society of those who were about me, so that, dinner-time excepted, I was entirely left to myself."

So the winter passed.

"The time when I could hope to receive a little more of my brother's instruction and attention was now drawing near ; for after Easter, Bath becomes very empty, only a few of his scholars, whose families were resident in the neighborhood, remaining. But I was greatly disappointed ; for, in consequence of the harassing and fatiguing life he had led during the winter months, he used to retire to bed with a basin of milk or glass of water, and SMITH'S *Harmonics* and *Optics*, FERGUSON'S *Astronomy*, etc., and so went to sleep buried under his favorite authors ; and his first thoughts on rising were how to obtain instruments for viewing those objects himself of which he had been reading. There being in one of the shops a two-and-a-half-foot Gregorian telescope to be let, it was for some time taken in requisition, and served not only for viewing the heavens, but for making experiments on its construction. . . . It soon appeared that my brother was not contented with knowing what former observers had seen, for he began to contrive a telescope eighteen or twenty feet long (I believe after HUYGHENS' description). . . . I was much hindered in my musical practice by my help being continually wanted in the execution of the various contrivances, and I had to amuse myself with making the tube of pasteboard for the glasses, which were to arrive from London, for at that time no optician had settled at Bath. But when all was finished, no one besides my brother could get a glimpse of Jupiter or Saturn, for the great length of the tube would not allow it to be kept in a straight line. This difficulty, however, was soon removed by substituting tin tubes. . . . My brother wrote to inquire the price of a reflecting mirror for (I believe) a five or six foot telescope. The answer was, there were none of so large a size, but a person offered to make one at a price much above what my brother thought proper to give. . . . About this time he bought of a Quaker, resident at Bath, who had formerly made attempts at polishing mirrors, all his rubbish of patterns, tools, hones, polishers, unfinished mirrors, etc., but all for small Gregorians, and none above two or three inches diameter.

"But nothing serious could be attempted, for want of time, till the beginning of June, when some of my brother's scholars were leaving Bath ; and then, to my sorrow, I saw almost every room turned into a workshop. A cabinet-maker making a tube and stands of all descriptions in a handsomely furnished drawing-room ; ALEX. putting up a huge turning machine (which he had brought in the autumn from Bristol, where he used to spend the summer) in a bedroom, for turning patterns, grinding glasses, and turning eye-pieces, etc. At the same time music durst not lie entirely dormant during the summer, and my brother had frequent rehearsals at home, where Miss FARINELLI, an Italian singer, was met by several of the principal performers he had engaged for the winter concerts."

Finally, in 1774, he had made himself a Gregorian telescope,* and had begun to view the heavens. He was then thirty-six years old.

The writer in the *European Magazine* describes this period :

"All this time he continued his astronomical observations, and nothing now seemed wanting to complete his felicity, but sufficient leisure to enjoy his telescopes, to which he was so much attached, that at the theatre he used frequently to run from the harpsichord to look at the stars, during the time between the acts."

* Probably on the model of one of SHORT's Gregorian telescopes, which were then the best instruments of the kind.

In an extract from his *Journal No.* 1, now at the rooms of the Royal Society, may be seen a copy of his first observation of the Nebula of *Orion*, on March 4, 1774. This was made with his five-and-a-half-foot Gregorian reflector.

It was at this time (1775), between the acts of the theatre, that he made his first review of the heavens, with a Newtonian telescope, of an aperture of four and a half inches and a magnifying power of 222 times. This telescope was one of the first made by himself. The review consisted of the examination of every star in the sky of the first, second, third, and fourth magnitudes, and of all planets visible. There are no records of these observations now extant, and they are noteworthy only as a preparation for more serious work.

He was carrying out his resolve to see everything for himself. His assiduity may be judged of by the fact that between 1774 and 1781 HERSCHEL had observed a single object—the Nebula of *Orion*—no less than fourteen times.

The success of his first telescopes incited him to new efforts. His house became a complete *atelier*, where everything that could tend to excellence in this manufacture was tried and re-tried a hundred different ways. When a difficulty arose, experiments were begun which continued till it was conquered. When a success was gained, it was prosecuted to the utmost.

In 1775 the first seven-foot reflector was made, in 1777 a ten-foot was finished, in 1778 a "very good" ten-foot took its place. It must not be thought that the telescopes mentioned were the only ones completed. On the contrary, they were but the best ones selected out of many.

In 1774 a new house had been engaged, which had "more room for workshops," and whose roof gave space for observing. The grass-plat near it was soon utilized to hold the stand of a twenty-foot telescope, which he had even then projected. His projects were unending, no success was final; his mind was at the height of activity; his whole effort was thrown into every undertaking.

The mirrors for all these telescopes were made by hand. Every portion of the grinding down to rough dimensions, the shaping to something near the correct form, the polishing till the accurately exact curves were obtained, all this must be done by hand. The machines for the purpose were not invented until 1788.*

ALEXANDER and WILLIAM worked together at this, but most of the work was done by the latter. The sister's part was to attend in the workshop and lend a hand wherever and whenever it was needed.

. . . "My time was taken up with copying music and practising, besides attendance on my brother when polishing, since by way of keeping him alive I was constantly obliged to feed him by putting the victuals by bits into his mouth. This was once the case when, in order to finish a seven-foot mirror, he had not taken his hands from it for sixteen hours together. In general he was never unemployed at meals, but was always at those times contriving or making drawings of whatever came

* For a description of the main points of HERSCHEL'S processes of making reflectors, which will illustrate his strong mechanical talents, see *Encyclopædia Britannica*, eighth edition, article *Telescope*.

in his mind. Generally I was obliged to read to him whilst he was at the turning-lathe, or polishing mirrors, *Don Quixote*, *Arabian Nights' Entertainment*, the novels of STERNE, FIELDING, etc.; serving tea and supper without interrupting the work with which he was engaged, . . . and sometimes lending a hand. I became, in time, as useful a member of the workshop as a boy might be to his master in the first year of his apprenticeship. . . . But as I was to take a part the next year in the oratorios, I had, for a whole twelvemonth, two lessons per week from Miss FLEMING, the celebrated dancing-mistress, to drill me for a gentlewoman (God knows how she succeeded). So we lived on without interruption. My brother ALEX. was absent from Bath for some months every summer, but when at home he took much pleasure in executing some turning or clockmaker's work for his brother."

News from Hanover put a sudden stop, for a time, to all these labors. The mother wrote, in the utmost distress, to say that DIETRICH had disappeared from his home, it was supposed with the intention of going to India "with a young idler not older than himself." His brother immediately left the lathe at which he was turning an eye-piece in cocoa-nut, and started for Holland, whence he proceeded to Hanover, failing to meet his brother, as he expected. Meanwhile the sister received a letter to say that DIETRICH was "laid up very ill" at an inn in Wapping. ALEXANDER posted to town, removed him to a lodging, and, after a fortnight's nursing, brought him to Bath, where, on his brother WILLIAM's return, he found him being well cared for by his sister.

About this time another change was made to the house 19 New King Street, which was the last move in Bath. It was here that the *Georgium Sidus* was discovered.

The music still went on. The oratorios of the *Messiah*, *Judas Maccabeus*, and *Samson* were to be performed under HERSCHEL's direction, with an orchestra of nearly one hundred pieces. The scores and vocal parts of these CAROLINA copied with her own hands, and the *soprani* were instructed by her, she being the leading soloist. Along with the music went the astronomy. Not only were new telescopes made, but they were made for immediate use.

The variable star *Mira Ceti* was observed, and a long series of lunar observations began.

"In 1779, 1780, and 1781 I measured the heights of about one hundred mountains of the moon, by three different methods.

" Some of these observations are given in *Philosophical Transactions*, vol. LXX., but most remain uncalculated in my journal till some proper opportunity." *

While HERSCHEL was measuring these lunar mountains, in December, 1779, he made by chance an acquaintance of much value to him. Dr. WILLIAM WATSON, a Fellow of the Royal Society, distinguished for his researches in electricity, happened to see him at his telescope, and this led to a visit and an invitation to HERSCHEL to join the Philosophical Society of Bath, then forming. This he gladly did, and it was of use to him in many ways.

He there formed acquaintance with men of his own way of thinking, and he himself became known. Better than all, he learned to

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* These have never been published, nor is it likely at this day, when our measuring instruments are so greatly improved, that they would be of any material value to science, although of interest as giving the proofs of HERSCHEL'S assiduity and skill. He was always more than the maker of telescopes, for he was never content until they were applied to the problems of astronomy.

measure himself with other men, and by his early papers read to the Society, he gained skill in putting his thoughts before his hearers. This skill he never lost, and the merely literary art of his memoirs would make his papers remarkable without their other merits. He is always clear, and in his early papers especially, he appeals to his particular audience—the Royal Society—in a way which shows that he is conscious of all its weaknesses as well as of its dignity. Later, his tone slightly changed. He became less anxious to win his audience, for he had become an authority. This knowledge lent a quiet strength to his style, but never induced the slightest arrogance of spirit or manner.

The Bath Philosophical Society has left no printed proceedings. HERSCHEL was one of its earliest members, and many papers were communicated to it by his hand. These appear to have been of a very miscellaneous nature. Some of them at least would be of the highest interest to us now.

In the *Philosophical Transactions* for 1789, p. 220, HERSCHEL tells us that he communicated to that Society "certain mathematical papers" relating to central forces other than the force of gravity, which are or may be concerned in the construction of the sidereal heavens. This early idea was still entertained by HERSCHEL in 1789, and the mathematical papers referred to must be contained in the *Minutes* of the Society, which on its dissolution were torn from the Minute-book and returned to the writers.

The earliest published writing of HERSCHEL is the answer to the prize question in the "Ladies' Diary" for 1779, proposed by the celebrated LANDEN, namely:

"The length, tension, and weight of a musical string being given, it is required to find how many vibrations it will make in a given time, when a small given weight is fastened to its middle and vibrates with it."

In the *Philosophical Transactions* of the Royal Society for 1780, are two papers of his. The title of the first is, *Astronomical Observations on the Periodical Star in Collo Ceti*, by Mr. WILLIAM HERSCHEL, of Bath. This was communicated to the Society by Dr.

WILLIAM WATSON, Jr., and was read May 11, 1780, at the same time as the other paper on the mountains of the moon. It is to be noted that HERSCHEL was at this time plain "Mr. WILLIAM HERSCHEL, of Bath." It was only in 1786 that he became "Dr. HERSCHEL," through the Oxford degree of LL.D.

Neither of these two papers is specially remarkable on its purely astronomical side. The problems examined were such as lay open before all, and the treatment of them was such as would naturally be suggested.

The second of these two contained, however, a short description of his Newtonian telescope, and he speaks of it with a just pride: "I believe that for distinctness of vision this instrument is perhaps equal to any that was ever made." He was, at least, certain of having obtained excellence in the making of his instruments.

In his next paper, however, read January 11, 1781, a subject is approached which shows a different kind of thought. It is the first obvious proof of the truth of the statement which he made long afterwards (1811), when he said: "A knowledge of the construction of the heavens has always been the ultimate object of my observations."

The title of this paper was *Astronomical Observations on the Rotation of the Planets round their Axes, made with a view to determine whether the Earth's diurnal motion is perfectly equable.* Here the question is a difficult and a remote one, and the method adopted for its solution is perfectly suitable in principle. It marks a step onward from mere observations to philosophizing upon their results. In practical astronomy, too, we note an advance. Not only are his results given, but also careful estimates of the errors to be feared in them, and a discussion of the sources of such errors. The same volume of the *Philosophical Transactions* which contains this paper, also contains another, *Account of a Comet,* read April 26, 1781. This comet was the major planet *Uranus,* or, as HERSCHEL named it, *Georgium Sidus.* He had found it on the night of Tuesday, March 13, 1781. "In examining the small stars in the neighborhood of H *Geminorum,* I perceived one that appeared visibly larger than the rest; being struck with its uncommon appearance, I compared it to H *Geminorum* and the small star in the quartile between *Auriga* and *Gemini*, and finding it so much larger than either of them, I suspected it to be a comet." The "comet" was observed over all Europe. Its orbit was computed by various astronomers, and its distance from the sun was found to be nineteen times that of our earth. This was no comet, but a new major planet. The discovery of the amateur astronomer of Bath was the most striking since the invention of the telescope. It had absolutely no parallel, for every other major planet had been known from time immemorial.*

The effect of the discoveries of GALILEO

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*ARAGO has implied that if HERSCHEL had directed his telescope to *Uranus* only eleven days earlier than he did, this discovery would have escaped him, since at that time (March 2, 1781) the planet was at its *station*, and had no motion relative to the star. This is an entire misconception, since the new planet was detected by its physical appearance, and not by its motion. Does any one suppose that "a new and singular star" like this would have been once viewed and then forgotten?

was felt almost more in the moral than in the scientific world. The mystic number of the planets was broken up by the introduction of four satellites to *Jupiter*. That *Venus* emulated the phases of our moon, overthrew superstition and seated the Copernican theory firmly. The discovery of "an innumerable multitude of fixed stars" in the Milky Way confounded the received ideas. This was the great mission of the telescope in GALILEO's hands.

The epoch of mere astronomical discovery began with the detection of the large satellite of *Saturn* by HUYGHENS, in 1655. Even then superstition was not dead. HUYGHENS did not search for more moons, because by that discovery he had raised the number of known satellites to six,* and because these, with the six planets, made "the perfect number twelve."

From 1671 to 1684 CASSINI discovered four more moons revolving about *Saturn*. Since 1684 no new body had been added to

* Four of *Jupiter*, one of the earth, and one of *Saturn*.

the solar system. It was thought complete for nearly a century.

In England, the remarkable discoveries of BRADLEY (1727–62) had been in the field of practical astronomy, and his example had set the key-note for further researches. France was just about beginning the brilliant period of her discoveries in mathematical astronomy, and had no observatory devoted to investigations like HERSCHEL'S, with the possible exception of DARQUIER'S and FLAUGERGUES'. The observatories of SCHROETER and VON HAHN, in Germany, were not yet active. The field which HERSCHEL was created to fill was vacant, the whole world over. It was especially so in England. The Royal Observatory at Greenwich, under MASKELYNE, a skilful observer, whose work was mostly confined to meridian observations, was no rival to a private observatory like HERSCHEL'S. The private observatories themselves were but small affairs; those of the king, at Kew, of Dr. WILSON, at Glasgow, of Mr. AUBERT, at Loampit Hill, of the Count VON BRUHL, in London, being perhaps the most important. The whole field was open. What was perhaps more remarkable, there was in England, during HERSCHEL'S lifetime, no astronomer, public or private, whose talents, even as an observer, lay in the same direction.

It hardly need be said that as a philosopher in his science, he had then no rival, as he has had none since. His only associates even, were MICHELL and WILSON.*

Without depreciating the abilities of the astronomers of England, his cotemporaries, we may fairly say that HERSCHEL stood a great man among a group of small ones.

Let us endeavor to appreciate the change effected in the state of astronomy not only

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* JOHN MICHELL had been a member of the Royal Society since 1760: he died in 1793. He was a philosophical thinker, as is shown by his memoirs on the distances of the stars, and by his invention of the method for determining the earth's density. It is not certain that he was personally known to HERSCHEL, although his writings were familiar to the latter.

ALEXANDER WILSON was Professor of Astronomy at Glasgow, and is chiefly known to us by his theory of the nature of the solar spots, which was adopted and enlarged by HERSCHEL. He died in 1786; but the families of WILSON and HERSCHEL remained close friends.

in England but in the whole world, simply by the discovery of *Uranus.* Suppose, for example, that the last planet in our system had been *Saturn.* No doubt HERSCHEL would have gone on. In spite of one and another difficulty, he would have made his ten-foot, his twenty-foot telescopes. His forty-foot would never have been built, and the two satellites which he found with it might not have been discovered. Certainly *Mimas* would not have been. His researches on the construction of the heavens would have been made; those were in his brain, and must have been ultimated. The mass of observations of *Saturn*, of *Jupiter*, of *Mars*, of *Venus*, would have been made and published. The researches on the sun, on the "invisible rays" of heat, on comets and nebulæ—all these might have been made, printed, and read.

But these would have gone into the *Philosophical Transactions* as the work of an amateur astronomer, "Mr. HERSCHEL, of Bath." They would have been praised, and they would have been doubted. It would have taken a whole generation to have appreciated them. They would have been severely tried, entirely on their merits, and finally they would have stood where they stand to-day—unrivalled. But through what increased labors these successes would have been gained! It is not merely that the patronage of the king, the subsidies for the forty-foot telescope (£4,000), the comparative ease of HERSCHEL's life would have been lacking. It is more than this. It would have been necessary for him to have created the audience to which he appealed, and to have conquered the most persistent of enemies—indifference.

Certainly, if HERSCHEL's mind had been other than it was, the discovery of *Uranus*, which brought him honors from every scientific society in the world, and which gave him authority, might have had a hurtful effect. But, as he was, there was nothing which could have aided his career more than this startling discovery. It was needed for him. It completed the solar system far more by affording a free play to a profoundly philosophical mind, than by occupying the vacant spaces beyond *Saturn.*

His opportunities would have been profoundly modified, though his personal worth would have been the same.

> "The Star that from the zenith darts its beams,
> Visible though it be to half the earth,
> Though half a sphere be conscious of its brightness,
> Is yet of no diviner origin,
> No purer essence, than the One that burns
> Like an untended wâtchfire, on the ridge
> Of some dark mountain ; or than those that seem
> Humbly to hang, like twinkling winter lamps,
> Among the branches of the leafless trees."

To show how completely unknown the private astronomer of Bath was at this time, I transcribe a sentence from BODE's account of the discovery of *Uranus.*

"In the *Gazette Littéraire* of June, 1781, this worthy man is called MERSTHEL ; in JULIUS' *Journal Encyclopédique*, HERTSCHEL ; in a letter from Mr. MASKELYNE to M. MESSIER, HERTHEL ; in another letter of MASKELYNE's to Herr MAYER, at Mannheim, HERRSCHELL ; M. DARQUIER calls him HERMSTEL. What may his name be ? He must have been born a *German.*" *

* *Berliner Jahrbuch*, 1784, p. 211. In the *Connaissance des Tems* for 1784 he is called "HOROCHELLE."

This obscurity did not long continue. The news spread quickly from fashionable Bath to London. On the 6th of December, 1781, HERSCHEL was elected a Fellow of the Royal Society, to which he was formally "admitted" May 30, 1782. He was forty-three years old.

He also received the Copley medal in 1781 for his "discovery of a new and singular star." *

. . . "He was now frequently interrupted by visitors who were introduced by some of his resident scholars, among whom I remember Sir HARRY ENGELFIELD, Dr. BLAGDEN, and Dr. MASKELYNE. With the latter he

* At the presentation Sir JOSEPH BANKS, the President of the Royal Society, said: "In the name of the Royal Society I present to you this gold medal, the reward which they have assigned to your successful labors, and I exhort you to continue diligently to cultivate those fields of science which have produced to you a harvest of so much honor. Your attention to the improvement of telescopes has already amply repaid the labor which you have bestowed upon them; but the treasures of the heavens are well known to be inexhaustible. Who can say but your new star, which exceeds *Saturn* in its distance from the sun, may exceed him as much in magnificence of attendance? Who knows what new rings, new satellites, or what other nameless and numberless phenomena remain behind, waiting to reward future industry and improvement?"

was engaged in a long conversation, which to me sounded like quarrelling, and the first words my brother said after he was gone were: 'That is a devil of a fellow.' . . .

"I suppose their names were often not known, or were forgotten; for it was not till the year 1782 or 1783 that a memorandum of the names of visitors was thought of." . . . "My brother now applied himself to perfect his mirrors, erecting in his garden a stand for his twenty-foot telescope; many trials were necessary before the required motions for such an unwieldy machine could be contrived. Many attempts were made by way of experiment before an intended thirty-foot telescope could be completed, for which, between whiles (not interrupting the observations with seven, ten, and twenty-foot, and writing papers for both the Royal and Bath Philosophical Societies), gauges, shapes, weight, etc., of the mirror were calculated, and trials of the composition of the metal were made. In short, I saw nothing else and heard nothing else talked of but these things when my brothers were together. ALEX. was always very alert, assisting when anything new was going forward, but he wanted perseverance, and never liked to confine himself at home for many hours together. And so it happened that my brother WILLIAM was obliged to make trial of my abilities in copying for him catalogues, tables, etc., and sometimes whole papers which were lent him for his perusal. Among them was one by Mr. MICHELL and a catalogue of CHRISTIAN MAYER, in Latin, which kept me employed when my brother was at the telescope at night. When I found that a hand was sometimes wanted when any particular measures were to be made with the lamp micrometer, etc., or a fire to be kept up, or a dish of coffee necessary during a long night's watching, I undertook with pleasure what others might have thought a hardship. . . . Since the discovery of the *Georgium Sidus* [March 13, 1781], I believe few men of learning or consequence left Bath before they had seen and conversed with its discoverer, and thought themselves fortunate in finding him at home on their repeated visits. Sir WILLIAM WATSON was almost an intimate, for hardly a day passed but he had something to communicate from the letters which he received from Sir JOSEPH BANKS, and other members of the Royal Society, from which it appeared that my brother was expected in town to receive the gold medal. The end of November was the most precarious season for absenting himself. But Sir WILLIAM WATSON went with him, and it was arranged so that they set out with the diligence at night, and by that means his absence did not last above three or four days, when my brother returned alone, Sir WILLIAM remaining with his father.

"Now a very busy winter was commencing; for my brother had engaged himself to conduct the oratorios conjointly with RONZINI, and had made himself answerable for the payment of the engaged performers, for his credit ever stood high in the opinion of every one he had to deal with. (He lost considerably by this arrangement.) But, though at times much harassed with business, the mirror for the thirty-foot reflector was never out of his mind, and if a minute could but be spared in going from one scholar to another, or giving one the slip, he called at home to see how the men went on with the furnace, which was built in a room below, even with the garden.

"The mirror was to be cast in a mould of loam, of which an immense quantity was to be pounded in a mortar and sifted through a fine sieve. It was an endless piece of work, and served me for many an hour's exercise; and ALEX. frequently took his turn at it, for we were all eager to do something towards the great undertaking. Even Sir WILLIAM WATSON would sometimes take the pestle from me when he found me in the work-room, where he expected to find his friend, in whose concerns he took so much interest that he felt much disappointed at not being allowed to pay for the metal. But I do not think my brother ever accepted pecuniary assistance from any one of his friends, and on this occasion he declined the offer by saying it was paid for already.

"Among the Bath visitors were many philosophical gentlemen who used to frequent the levées at St. James's, when in town. Colonel WALSH, in particular, informed my brother that from a conversation he had had with His Majesty, it appeared that in the spring he was to come with his seven-foot telescope to the king. Similar reports he received from many others, but they made no great impression nor caused any interruption in his occupation or study, and as soon as the season for the concerts was over, and the mould, etc., in readiness, a day was set apart for casting, and the metal was in the furnace. Unfortunately it began to leak at the moment when ready for pouring, and both my brothers and the caster, with his men, were obliged to run out at opposite doors, for the stone flooring (which ought to have been taken up) flew about in all directions as high as the ceiling. Before the second casting was attempted, everything which could insure success had been attended to, and a very perfect metal was found in the mould.

"But a total stop and derangement now took place, and nearly six or seven months elapsed before my brother could return to the undisturbed enjoyment of his instruments and observations. For one morning in Passion Week, as Sir WILLIAM WATSON was with my brother, talking about the pending journey to town, my eldest nephew arrived to pay us a visit, and brought the confirmation that his uncle was expected with his instrument in town. . . . We had not one night in the week, except Friday, but what was set apart for an oratorio either at Bath or Bristol. Soon after Easter, a new organ being erected in St. James's Church, it was opened with two performances of the 'Messiah;' this again took up some of my brother's time." . . .

In May of 1782 HERSCHEL went to London.

"But when almost double the time had elapsed which my brother could safely be absent from his scholars, ALEX., as well as myself, were much at a loss how to answer their inquiries, for, from the letters we received, we could learn nothing but that he had been introduced to the king and queen, and had permission to come to the concerts at Buckingham House, where the king conversed with him about astronomy."

It was during his absence at this time that the three following letters were written and received:

"DEAR LINA :—

"I have had an audience of His Majesty this morning, and met with a very gracious reception. I presented him with the drawing of the solar system, and had the honor of explaining it to him and the queen. My telescope is in three weeks' time to go to Richmond, and meanwhile to be put up at Greenwich, where I shall accordingly carry it to-day. So you see, LINA, that you must not think of seeing me in less than a month. I shall write to Miss LEE myself; and other scholars who inquire for me, you may tell that I cannot wait on them till His Majesty shall be pleased to give me leave to return, or rather to dismiss me, for till then I must attend. I will also write to Mr. PALMER to acquaint him with it.

"I am in a great hurry, therefore can write no more at present. Tell ALEXANDER that everything looks very likely as if I were to stay here. The king inquired after him, and after my great speculum. He also gave me leave to come to hear the GRIESBACHS play at the private concert which he has every evening. My having seen the king need not be kept a secret, but about my staying here it will be best not to say anything, but only that I must remain here till His Majesty has observed the planets with my telescope.

"Yesterday I dined with Colonel WALSH, who inquired after you. There were Mr. AUBERT and Dr. MASKELYNE. Dr. MASKELYNE in public declared his obligations to me for having introduced to them the high powers, for Mr. AUBERT has so much succeeded with them that he says he looks down upon 200, 300, or 400 with contempt, and immediately begins with 800. He has used 2,500 very completely, and seen my fine double stars with them. All my papers are printing, with the postscript and all, and are allowed to be very valuable. You see, LINA, I tell you all these things. You know vanity is not my foible, therefore I need not fear your censure. Farewell.

"I am, your affectionate brother,

"WM. HERSCHEL.

"Saturday Morning,

"probably *May* 25, 1782."

TO MISS HERSCHEL.

"Monday Evening, *June* 3, 1782.

"DEAR LINA :—

"I pass my time between Greenwich and London agreeably enough, but am rather at a loss for work that I like. Company is not always pleasing, and I would much rather be polishing a speculum. Last Friday I was at the king's concert to hear GEORGE play. The king spoke to me as soon as he saw me, and kept me in conversation for half an hour. He asked GEORGE to play a solo-concerto on purpose that I might hear him; and GEORGE plays extremely well, is very much improved, and the king likes him very much. These two last nights I have been star-gazing at Greenwich with Dr. MASKELYNE and Mr. AUBERT. We have compared our telescopes together, and mine was found very superior to any of the Royal Observatory. Double stars which they could not see with their instruments I had the pleasure to show them very plainly, and my mechanism is so much approved of that Dr. MASKELYNE has already ordered a model to be taken from mine, and a stand to be made by it to his reflector. He is, however, now so much out of love with his instrument that he begins to doubt whether it *deserves* a new stand.

"I am introduced to the best company. To-morrow I dine at Lord PALMERSTON'S, next day with Sir JOSEPH BANKS, etc., etc. Among opticians and astronomers nothing now is talked of but *what they call* my great discoveries. Alas! this shows how far they are behind, when such trifles as I have seen and done are called *great*. Let me but get at it again! I will make such telescopes, and see such things—that is, I will endeavor to do so."

TO MISS HERSCHEL.

"*July* 3, 1782.

"DEAR CAROLINA :—

"I have been so much employed that you will not wonder at my not writing sooner. The letter you sent me last Monday came very safe to me. As Dr. WATSON has been so good as to acquaint you and ALEXANDER with my situation, I was still more easy in my silence to you. Last night the King, the Queen, the Prince of Wales, the Princess Royal, Princess SOPHIA, Princess AUGUSTA, etc., Duke of MONTAGUE, Dr. HEBERDEN, M. DE LUC, etc., etc., saw my telescope, and it was a very fine evening. My instrument gave general satisfaction. The king has very good eyes, and enjoys observations with telescopes exceedingly.

"This evening, as the king and queen are gone to Kew, the princesses were desirous of seeing my telescope, but wanted to know if it was possible to see without going out on the grass, and were much pleased when they heard that my telescope could be carried into any place they liked best to have it. About eight o'clock it was moved into the queen's apartments, and we waited some time in hopes of seeing *Jupiter* or *Saturn*. Meanwhile I showed the princesses, and several other ladies who were present, the speculum, the micrometers, the movements of the telescopes, and other things that seemed to excite their curiosity. When the evening appeared to be totally unpromising, I proposed an artificial *Saturn* as an object, since we could not have the real one. I had beforehand prepared this little piece, as I guessed by the appearance of the weather in the afternoon we should have no stars to look at. This being accepted with great pleasure, I had the lamps lighted up which illuminated the picture of a *Saturn* (cut out in pasteboard) at the bottom of the garden wall. The effect was fine, and so natural that the best astronomer might have been deceived. Their royal highnesses and other ladies seemed to be much pleased with the artifice.

"I remained in the queen's apartment with the ladies till about half after ten ; when in conversation with them I found them extremely well instructed in every subject that was introduced, and they seemed to be most amiable characters. To-morrow evening they hope to have better luck, and nothing will give me greater happiness than to be able to show them some of those beautiful objects with which the heavens are so gloriously ornamented.

CAROLINA'S diary goes on:

"Sir WILLIAM WATSON returned to Bath after a fortnight or three weeks' stay. From him we heard that my brother was invited to Greenwich with the telescope, where he was met by a numerous party of astronomical and learned gentlemen, and trials of his instrument were made. In these letters he complained of being obliged to lead an idle life, having nothing to do but to pass between London and Greenwich. Sir WILLIAM received many letters, which he was so kind as to communicate to us. By these, and from those to ALEXANDER or to me, we learned that the king wished to see the telescope at Windsor. At last a letter, dated July 2, arrived from THERESE, and from this and several succeeding ones we gathered that the king would not suffer my brother to return to his profession again, and by his writing several times for a supply of money we could only suppose that he himself was in uncertainty about the time of his return.

"In the last week of July my brother came home, and immediately prepared for removing to Datchet, where he had taken a house with a garden and grass-plat annexed, quite suitable for the purpose of an observing-place. Sir WILLIAM WATSON spent nearly the whole time at our house, and he was not the only friend who truly grieved at my brother's going from Bath; or feared his having perhaps agreed to no very advantageous offers; their fears were, in fact, not without reason. . . . The prospect of entering again on the toils of teaching, etc., which awaited my brother at home (the months of leisure being now almost gone by), appeared to him an intolerable waste of time, and by way of alternative he chose to be royal astronomer, with a salary of £200 a year. Sir WILLIAM WATSON was the only one to whom the sum was mentioned, and he exclaimed, 'Never bought monarch honor so cheap!' To every other inquirer, my brother's answer was that the king had provided for him."

On the 1st of August, 1782, the family removed to Datchet. The last musical duty was performed on Whit-Sunday, 1782, in St. Margaret's Chapel, Bath, when the anthem for the day was of HERSCHEL'S own composition.

The end of the introductory epoch of his life is reached. Henceforth he lived in his observatory, and from his forty-fourth year onwards he only left it for short periods to go to London to submit his classic memoirs to the Royal Society. Even for these occasions he chose periods of moonlight, when no observations could be made.

He was a private man no longer. Henceforth he belongs to the whole world.

CHAPTER III.

LIFE AT DATCHET, CLAY HALL, AND SLOUGH; 1782–1822.

THE new house at Datchet, which was occupied from 1782 till 1785, was a source of despair to CAROLINA HERSCHEL, who looked upon its desolate and isolated condition with a housekeeper's eyes. This was nothing to her brother, who gayly consented to live upon "eggs and bacon," now that he was free at last to mind the heavens. The ruinous state of the place had no terrors in his eyes, for was there not a laundry which would serve as a library, a large stable which was just the place for the grinding of mirrors, and a grass-plat for the small twenty-foot reflector?

Here they set to work at astronomy; the

brother with the twenty-foot, the sister aiding him, and at odd times sweeping for comets. In the course of her life she discovered no less than eight, and five of these were first seen by her.

In 1787 HERSCHEL wrote his paper "On three Volcanoes in the Moon," which he had observed in April of that year. In this he mentions previous observations of the same sort. I do not remember that the following account of these has ever been put on record in English. Baron VON ZACH writes from London to BODE:*

"Probably you have heard also of the volcanoes in the moon, which HERSCHEL has observed. . . . I will give you an account of it as I heard it from his own lips. Dr. LIND, a worthy physician in Windsor, who has made himself known through his two journeys in China, and who is a friend of our HERSCHEL'S, was with his wife one evening on a visit to HERSCHEL in Datchet [1783, May 4]. On this evening there was to be an occultation of a star at the moon's dark limb. This was observed by HERSCHEL and Doctor LIND. Mrs. LIND wished also to see what was occurring, and placed herself at a telescope and watched attentively.

* BODE'S *Jahrbuch*, 1788, p. 144.

"Scarcely had the star disappeared before Mrs. LIND thought she saw it again, and exclaimed that the star had gone in front of, and not behind the moon. This provoked a short astronomical lecture on the question, but still she would not credit it, because she *saw* differently. Finally HERSCHEL stepped to the telescope, and in fact he saw a bright point on the dark disc of the moon, which he followed attentively. It gradually became fainter and finally vanished." . . .

The life at Datchet was not free from its annoyances.

"Much of my brother's time was taken up in going, when the evenings were clear, to the queen's lodge, to show the king, etc., objects through the seven-foot. But when the days began to shorten, this was found impossible, for the telescope was often (at no small expense and risk of damage) obliged to be transported in the dark back to Datchet, for the purpose of spending the rest of the night with observations on double stars for a second catalogue. My brother was, besides, obliged to be absent for a week or ten days, for the purpose of bringing home the metal of the cracked thirty-foot mirror, and the remaining materials from his work-room. Before the furnace was taken down at Bath, a second twenty-foot mirror, twelve inches diameter, was cast, which happened to be very fortunate, for on the 1st of January, 1783, a very fine one cracked by frost in the tube.

. . . "In my brother's absence from home I was, of course, left alone to amuse myself with my own thoughts, which were anything but cheerful. I found I was to be trained for an assistant astronomer, and, by way of encouragement, a telescope adapted for 'sweeping,' consisting of a tube with two glasses, such as are commonly used in a 'finder,' was given me. I was 'to sweep for comets,' and I see, by my journal, that I began August 22d, 1782, to write down and describe all remarkable appearances I saw in my 'sweeps,' which were horizontal. But it was not till the last two months of the same year that I felt the least encouragement to spend the star-light nights on a grass-plot covered with dew or hoar-frost, without a human being near enough to be within call. I knew too little of the real heavens to be able to point out every object so as to find it again, without losing much time by consulting the Atlas. But all these troubles were removed when I knew my brother to be at no great distance making observations, with his various instruments, on double stars, planets, etc., and when I could have his assistance immediately if I found a nebula or cluster of stars, of which I intended to give a catalogue; but, at the end of 1783, I had only marked fourteen, when my sweeping was interrupted by being employed to write down my brother's observations with the large twenty-foot. I had, however, the comfort to see that my brother was satisfied with my endeavors to assist him when he wanted another person either to run to the clocks, write down a memorandum, fetch and carry instruments, or measure the ground with poles, etc., etc., of which something of the kind every moment would occur. For the assiduity with which the measurements on the diameter of the *Georgium Sidus*, and observations of other planets, double stars, etc., etc., were made, was incredible, as may be seen by the various papers that were given to the Royal Society in 1783, which papers were written in the daytime, or when cloudy nights interfered. Besides this, the twelve-inch speculum was perfected before the spring, and many hours were spent at the turning-bench, as not a night clear enough for observing ever passed but that some improvements were planned for perfecting the mounting and motions of the various instruments then in use, or some trials were made of new constructed eye-pieces, which were mostly executed by my brother's own hands. Wishing to save his time, he began to have some work of that kind done by a watchmaker who had retired from business and lived on Datchet Common; but the work was so bad, and the charges so unreasonable, that he could not be employed. It was not till some time afterwards, in his frequent visits to the meetings of the Royal Society (made in moonlight nights), that he had an opportunity of looking about for mathematical workmen, opticians, and founders. But the work seldom answered expectation, and it was kept, to be executed with improvements by ALEXANDER during the few months he spent with us.

"The summer months passed in the most active preparation for getting the large twenty-foot ready against the next winter. The carpenters and smiths of Datchet were in daily requisition, and, as soon as patterns for tools and mirrors were ready, my brother went to town to have them cast, and, during the three or four months ALEXANDER could be absent from Bath, the mirrors and optical parts were nearly completed.

"But that the nights after a day of toil were not given to rest, may be seen by the observations on *Mars*, of which a paper, dated December 1, 1783, was given to the Royal Society. Some trouble, also, was often thrown away, during those nights, in the attempt to teach me to remeasure double stars with the same micrometers with which former measures had been taken, and the small twenty-foot was given me for that purpose. . . . I had also to ascertain their places by a transit instrument lent for that purpose by Mr. DALRYMPLE; but, after many fruitless attempts, it was seen that the instrument was, perhaps, as much in fault as my observations."

In 1783 HERSCHEL says:

"I have now finished my third review of the heavens. The first was made with a Newtonian telescope something less than seven feet focal length, a power of 222, and an aperture of four and a half inches. It extended only to stars of the first, second, third, and fourth magnitudes. My second review was made with an instrument much superior to the other, of 85.2 inches focus, 6.2 inches aperture, and power 227. It extended to all the stars of HARRIS's maps and the telescopic ones near them, as far as the eighth magnitude. The Catalogue of Double Stars and the discovery of the *Georgium Sidus*, were the results of that review. The third was with the same instrument and aperture, but with a power of 460. This review extended to all the stars of FLAMSTEED's Catalogue, together with every small star about them, to the amount of a great many thousands of stars. I have, many a night, in the course of eleven or twelve hours of observation, carefully and singly examined not less than 400 celestial objects, besides taking measures, and sometimes viewing a particular star for half an hour together."

The fourth review began with the twenty-foot, in 1784.

"My brother began his series of sweeps when the instrument was yet in a very unfinished state, and my feelings were not very comfortable when every moment I was alarmed by a crack or fall, knowing him to be elevated fifteen feet or more on a temporary cross-beam, instead of a safe gallery. The ladders had not even their braces at the bottom; and one night, in a very high wind, he had hardly touched the ground before the whole apparatus came down. Some laboring men were called up to help in extricating the mirror, which was, fortunately, uninjured, but much work was cut out for carpenters next day. I could give a pretty long list of accidents which were near proving fatal to my brother as well as myself. To make observations with such large machinery, where all around is in darkness, is not unattended with danger, especially when personal safety is the last thing with which the mind is occupied ; even poor PIAZZI did not go home without getting broken shins by falling over the rack-bar.

"In the long days of the summer months many ten and seven foot mirrors were finished ; there was nothing but grinding and polishing to be seen. For ten-foot, several had been cast with ribbed backs, by way of experiment, to reduce the weight in large mirrors. In my leisure hours I ground seven-foot and plain mirrors from rough to fining down, and was *indulged* with polishing and the last finishing of a very beautiful mirror for Sir WILLIAM WATSON.

"An account of the discoveries made with the twenty-foot and the improvements of the mechanical parts of the instrument during the winter of 1785 is given with the catalogue of the first 1,000 new nebulæ. By which account it must plainly appear that the expenses of these improvements, and those which were yet to be made in the apparatus of the twenty-foot (which, in fact, proved to be a model of a larger instrument), could not be supplied out of a salary of £200 a year, especially as my brother's finances had been too much reduced during the six months before he received his *first* quarterly payment of *fifty pounds* (which was Michaelmas, 1782). Travelling from Bath to London, Greenwich, Windsor, backwards and forwards, transporting the telescope, etc., breaking up his establishment at Bath and forming a new one near the court, all this, even leaving such personal conveniences as he had for many years been used to, out of the question, could not be obtained for a trifle; a good large piece of ground was required for the use of the instruments, and a habitation in which he could receive and offer a bed to an astronomical friend, was necessary after a night's observation.

"It seemed to be supposed that enough had been done when my brother was enabled to leave his profession that he might have time to make and sell telescopes. The king ordered four ten-foot himself, and many seven-foot besides had been bespoke, and much time had already been expended on polishing the mirrors for the same. But all this was only retarding the work of a thirty or forty foot instrument, which it was my brother's chief object to obtain as soon as possible; for he was then on the wrong side of forty-five, and felt how great an injustice he would be doing to himself and to the cause of astronomy by giving up his time to making telescopes for other observers.

"Sir WILLIAM WATSON, who often in the lifetime of his father came to make some stay with us at Datchet, saw my brother's difficulties, and expressed great dissatisfaction. On his return to Bath he met, among the visitors there, several belonging to the court, to whom he gave his opinion concerning his friend and his situation very freely. In consequence of this, my brother had soon after, through Sir J. BANKS, the promise that

£2,000 would be granted for enabling him to make himself an instrument.

"Immediately every preparation for beginning the great work commenced. A very ingenious smith (CAMPION), who was seeking employment, was secured by my brother, and a temporary forge erected in an upstairs room."

The sale of ~~these telescopes of~~ HERSCHEL'S telescopes must have produced a large sum, for he had made before 1795 more than two hundred seven-feet, one hundred and fifty ten-feet, and eighty twenty-feet mirrors. For many of the telescopes sent abroad no stands were constructed. The mirrors and eye-pieces alone were furnished, and a drawing of the stand sent with them by which the mirrors could be mounted.

In 1785 the cost of a seven-foot telescope, six and four-tenths inches aperture, stand, eye-pieces, etc., complete, was two hundred guineas, a ten-foot was six hundred guineas, and a twenty-foot about 2,500 to 3,000 guineas. He had made four ten-foot telescopes like this for the king. In 1787 SCHROETER got the mirrors and eye-pieces only for a four-and-three-quarter-inch reflector for five guineas; those for his seven-foot telescope were twenty-three guineas. Later a seven-foot telescope, complete, was sold for one hundred guineas, and the twenty-five-foot reflector, made for the Madrid observatory, cost them 75,000 francs = $15,000.* It was ordered in 1796, but not delivered for several years, the Spanish government being short of money. For a ten and a seven foot telescope, the Prince of Canino paid £2,310.

VON MAGELLAN writes to BODE concerning a visit to HERSCHEL: †

"I spent the night of the 6th of January at HERSCHEL'S, in Datchet, near Windsor, and had the good luck to hit on a fine evening. He has his twenty-foot Newtonian telescope in the open air and mounted in his garden very simply and conveniently. It is moved by an assistant, who stands below it. . . . Near the instrument is a clock regulated to sidereal time. . . . In the room near it sits HERSCHEL'S sister, and she has FLAMSTEED'S Atlas open before her. As he gives her the word, she writes down the declination and right ascension and the other circumstances of the observation. In

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* ZACH'S *Monatlich Correspondenz*, 1802, p. 56.

† BODE'S *Jahrbuch*, 1788, p. 161.

this way HERSCHEL examines the whole sky without omitting the least part. He commonly observes with a magnifying power of one hundred and fifty, and is sure that after four or five years he will have passed in review every object above our horizon. He showed me the book in which his observations up to this time are written, and I am astonished at the great number of them. Each sweep covers 2° 15′ in declination, and he lets each star pass at least three times through the field of his telescope, so that it is impossible that anything can escape him. He has already found about 900 double stars and almost as many nebulæ. I went to bed about one o'clock, and up to that time, he had found that night four or five new nebulæ. The thermometer in the garden stood at 13° Fahrenheit; but, in spite of this, HERSCHEL observes the whole night through, except that he stops every three or four hours and goes in the room for a few moments. For some years HERSCHEL has observed the heavens every hour when the weather is clear, and this always in the open air, because he says that the telescope only performs well when it is at the same temperature as the air. He protects himself against the weather by putting on more clothing. He has an excellent constitution, and thinks about nothing else in the world but the celestial bodies. He has promised me in the most cordial way, entirely in the service of astronomy, and without thinking of his own interest, to see to the telescopes I have ordered for European observatories, and he will himself attend to the preparation of the mirrors."

IN

It was at this time, 1783, May 8, that HERSCHEL married. His wife was the daughter of Mr. JAMES BALDWIN, a merchant of the city of London, and the widow of JOHN PITT, Esq. She is described as a lady of singular amiability and gentleness of character. She was entirely interested in his scientific pursuits, and the jointure which she brought removed all further anxiety about money affairs. They had but one child, JOHN FREDERICK WILLIAM, born March 7, 1792.*

The house at Datchet became more and

* Through Sir JOHN HERSCHEL there is preserved to us an incident of his early boyhood, which shows the nature of the training his young mind received in the household at Slough.

Walking with his father, he asked him "What was the oldest of all things?" The father replied, after the Socratic manner, "And what do you suppose is the oldest of all things?" The boy was not successful in his answers, whereon the old astronomer took up a small stone from the garden walk: "There, my child, there is the oldest of all the things that I certainly know." On another occasion the father asked his son, "What sort of things do you think are most alike?" The boy replied, "The leaves of the same tree are most like each other." "Gather, then, a handful of leaves from that tree," rejoined the philosopher, "and choose two which are alike."—*Monthly Notices Royal Astronomical Society*, vol. xxxii., page 123.

more unfit for the needs of the family, and in June, 1785, a move was made to Clay Hall, in Old Windsor. The residence here was but short, and finally a last change was made to Slough on April, 3d, 1786.

The ardor of the work during these years can be judged of by a single sentence from CAROLINA HERSCHEL's diary:

"The last night at Clay Hall was spent in sweeping till daylight, and by the next evening the telescope stood ready for observation at Slough."

From 1786 until his death, HERSCHEL remained at Slough; his life, truly speaking, was in his observatory.

It is indeed true, as ARAGO has said in his eloquent tribute to him: "On peut dire hardiment du jardin et de la petite maison de Slough, que c'est le lieu du monde où il a été fait le plus de découvertes. Le nom de ce village ne périra pas; les sciences le transmettront religieusement à nos derniers neveux."

HERSCHEL's first contribution to the *Philosophical Transactions* was printed in the volume for 1780, his last in that for 1818. Of these thirty-nine volumes, there are only two (1813 and 1817) which contain no paper from his hand, and many volumes contain more than one, as he published no less than sixty-eight memoirs in this place.

And yet it must not be thought that his was an austere and grave existence. Music, which he loved to enthusiasm, was still a delight to him. All the more that his devotion was free. The glimpses which we get of his life with his friends show him always cheerful, ardent, and devoted. Even in his later years, he had not lost a "boyish earnestness to explain;" his simplicity and the charm of his manner struck every one.

"HERSCHEL, you know, and everybody knows, is one of the most pleasing and well-bred natural characters of the present age," says Dr. BURNEY, who had opportunity to know.

The portrait which is given in the frontispiece must have been painted about this time (1788), and the eager, ardent face shows his inner life far better than any words can do.

Even in his scientific writings, which everything conspired to render grave and sober, the almost poetic nature of his mind shows forth.] In one of his (unpublished) note-books, now in the Royal Society's library, I found this entry :

"640th Sweep—November 28, 1786.—The nebula of *Orion*, which I saw by the front view, was so glaring and beautiful that I could not think of taking any place of its extent."

He was quite alone under the perfectly silent sky when this was written, and he was at his post simply to make this and other such observations. But the sky was beautiful to him, and his faithful sister, CAROLINA, sitting below, has preserved for us the words as they dropped from his lips.

On the 11th of January, 1787, HERSCHEL discovered two satellites to *Uranus*.

After he had well assured himself of their existence, but before he communicated his discovery to the world, he made this crucial test. He prepared a sketch of *Uranus* attended by his two satellites, as it would appear on the night of February 10, 1787, and when the night came, "the heavens displayed the original of my drawings, by showing in the situation I had delineated them *the Georgian planet attended by two satellites.* I confess that this scene appeared to me with additional beauty, as the little secondary planets seemed to give a dignity to the primary one which raises it into a more conspicuous situation among the great bodies of the solar system." . . .

In a memoir of 1789, he has a few sentences which show the living way in which the heavens appeared to him :

"This method of viewing the heavens seems to throw them into a new kind of light.

"They are now seen to resemble a luxuriant garden, which contains the greatest variety of productions in different flourishing beds ; and one advantage we may at least reap from it is, that we can, as it were, extend the range of our experience to an immense duration. For is it not almost the same thing whether we live successively to witness the germination, blooming, foliage, fecundity, fading, withering, and corruption of a plant, or whether a vast number of specimens selected from every stage through which the plant passes in the course of its existence be brought at once to our view?"

[The thought here is no less finely expressed than it is profound. The simile is perfect, if we have the power to separate among the vast variety each state of being from every other, and if the very luxuriance of illustration in the heavens does not bewilder and overpower the mind. It was precisely this discriminating power that HERSCHEL possessed in perfection.]

There is a kind of humor in the way he records a change of opinion:

"I formerly supposed the surface of *Saturn's* ring to be rough, owing to luminous points like mountains seen on it, till one of these was kind enough to venture off the edge of the ring and appear as a satellite."

In 1782 he replies with a certain concealed sharpness to the idea that he used magnifying powers which were too high. There is a tone almost of impatience, as if he were conscious he was replying to a criticism based on ignorance:

"We are told that we gain nothing by magnifying too much. I grant it; but shall never believe I magnify too much till by experience I find that I can see better with a lower power." (1782.)

By 1786, when he returns to this subject, in answer to a formal request to explain his use of high magnifiers, he is quite over any irritation, and treats the subject almost with playfulness:

"Soon after my first essay of using high powers with the Newtonian telescope, I began to doubt whether an opinion which has been entertained by several eminent authors, 'that vision will grow indistinct when the optic pencils are less than the fiftieth part of an inch,' would hold good in all cases. I perceived that according to this criterion I was not entitled to see distinctly with a power of much more than about 320 in a seven-foot telescope of an aperture of six and four-tenths inches, whereas in many experiments I found myself very well pleased with magnifiers which far exceeded such narrow limits. This induced me, as it were, by way of apology to myself for seeing well where I ought to have seen less distinctly, to make a few experiments."

It is needless to say that these experiments proved that from the point of view taken by HERSCHEL, he was quite right, and that his high powers had numerous valuable applications. He goes on to say:

"Had it not been for a late conversation with some of my highly esteemed and learned friends, I might probably have left the papers on which these experiments were recorded, among the rest of those that are laid aside, when they have afforded me the information I want."

The last sentence seems to be a kind of notice to his learned friends that there is yet more unsaid. As a warning to those to whose criticisms he had replied, he gives them this picture of the kind of assiduity which will be required, if some of his observations on double stars are to be repeated:

"It is in vain to look for these stars if every circumstance is not favorable. The observer as well as the instrument must have been long enough out in the open air to acquire the same temperature. In very cold weather an hour at least will be required." (1782.)

We may gain some further insight into his character from the following chance extracts from his writings:

"I have all along had truth and reality in view as the sole object of my endeavors." (1782.)

"Not being satisfied when I thought it possible to obtain more accurate measures, I employed [a more delicate apparatus]." (1783.)

"To this end I have already begun a series of observations upon several zones of double stars, and should the result of them be against these conjectures, I shall be the first to point out their fallacy." (1783.)

"There is a great probability of succeeding still farther in this laborious but delightful research, so as to be able at last to say not only how much the annual parallax *is not*, but how much it really *is*." (1782.)

The nature of his philosophizing, and the limits which he set to himself, may be more clearly seen in further extracts:

"By taking more time [before printing these observations] I should undoubtedly be enabled to speak more confidently of the *interior construction of the heavens*, and of its various *nebulous* and sidereal strata. As an apology for this prematurity it may be said that, the end of all discoveries being communication, we can never be too ready in giving facts and observations, whatever we may be in reasoning upon them." (1785.)

"In an investigation of this delicate nature we ought to avoid two opposite extremes. If we indulge a fanciful imagination, and build worlds of our own, we must not wonder at our going wide from the path of truth and nature. On the other hand, if we add observation to observation without attempting to draw not only certain conclusions but also conjectural views from them, we offend against the very end for which only observations ought to be made. I will endeavor to keep a proper medium, but if I should deviate from that, I could wish not to fall into the latter error." (1785.)

"As observations carefully made should always take the lead of theories, I shall not be concerned if what I have to say contradicts what has been said in my last paper on this subject." (1790.)

No course of reasoning could be more simple, more exact, more profound, and more beautiful than this which follows:

"As it has been shown that the spherical figure of a cluster is owing to the action of central powers, it follows that those clusters which, *cæteris paribus*, are the most complete in this figure, must have been the longest exposed to the action of these causes. Thus the maturity of a sidereal system may be judged from the disposition of the component parts.

"Hence planetary nebulæ may be looked on as very aged. Though we cannot see any individual nebula pass through all its stages of life, we can select particular ones in each peculiar stage." (1789.)

There is something almost grandiose and majestic in his statement of the ultimate destiny of the Galaxy:

"To him the fates were known
Of orbs dim hovering on the skirts of space."

"—Since the stars of the Milky Way are permanently exposed to the action of a power whereby they are irresistibly drawn into groups, we may be certain that from mere clustering stars they will be gradually compressed, through successive stages of accumulation, till they come up to what may be called the ripening period of the globular form, and total insulation; from which it is evident that the Milky Way must be finally broken up and cease to be a stratum of scattered stars.

"The state into which the incessant action of the clustering power has brought it at present, is a kind of chronometer that may be used to measure the time of its past and future existence; and although we do not know the rate of going of this mysterious chronometer, it is nevertheless certain that since the breaking up of the Milky Way affords a proof that it cannot last forever, it equally bears witness that its past duration cannot be admitted to be infinite." (1814.)

HERSCHEL's relations with his cotemporaries were usually of the most pleasant character, though seldom intimate. This peace was broken but by one unpleasant occurrence. In the *Philosophical Transactions* for 1792, SCHROETER had communicated a series of observations made with one of HERSCHEL's own telescopes on the atmospheres of *Venus*, the Moon, etc. It was not only an account of phenomena which had been seen; it was accompanied by measures, and the computations based on these led to heights and dimensions for mountains on *Venus* which were, to say the least, extravagant. The adjective will not seem too strong when we say that the very existence of the mountains themselves is to-day more than doubtful.

The appearances seen by SCHROETER were described by him in perfectly good faith, and similar ones have been since recorded. His reasoning upon them was defective, and the measures which he made were practically valueless. This paper, printed in the *Transactions* of the Royal Society, to which

SCHROETER had not before contributed, appears to have irritated HERSCHEL.

No doubt there were not wanting members of his own society who hinted that on the Continent, too, there were to be found great observers, and that here, at least, HERSCHEL had been anticipated even in his own field. I have always thought that the memoir of HERSCHEL which appeared in the next volume of the *Transactions* (1793), *Observations on the Planet Venus*, was a rejoinder intended far more for the detractors at home than for the astronomer abroad. The review is conceived in a severe spirit. The first idea seems to be to crush an opposition which he feels. The truth is established, but its establishment is hardly the *first* object.

It seems as if HERSCHEL had almost allowed himself to be forced into a position of arrogance, which his whole life shows was entirely foreign to his nature. All through the review he does not once mention SCHROETER's name. He says:

"A series of observations on *Venus*, begun by me in April, 1777, has been continued down to the present time. . . . The result of my observations would have been communicated long ago if I had not flattered myself with the hope of some better success concerning the diurnal motion of *Venus*, which has still eluded my constant attention as far as concerns its period and direction. . . . Even at this present time I should hesitate to give the following extracts if it did not seem incumbent on me to examine by what accident I came to overlook mountains in this planet of such enormous height as to exceed four, five, or even six times the perpendicular height of Chimboraço, the highest of our mountains. . . . The same paper contains other particulars concerning *Venus* and *Saturn*. All of which being things of which I have never taken any notice, it will not be amiss to show, by what follows, that neither want of attention, nor a deficiency of instruments, would occasion my not perceiving these mountains of more than twenty-three miles in height, this jagged border of *Venus*, and these flat, spherical forms on *Saturn*."]

The reply of SCHROETER (1795) is temperate and just. It does him honor, and he generously gives full justice to his critic.

It would hardly be worth while to mention this slight incident if it were not that during these years there certainly existed a feeling that HERSCHEL undervalued the labors of his cotemporaries.

This impression was fostered no doubt by his general habit of not quoting previous authorities in the fields which he was working.

A careful reading of his papers will, I think, show that his definite indebtedness to his *cotemporaries* was vanishingly small. The work of MICHELL and WILSON he alludes to again and again, and always with appreciation. Certainly he seems to show a vein of annoyance that the papers of CHRISTIAN MAYER, *De novis in cœlo sidereo phænomenis* (1779), and *Beobachtungen von Fixsterntrabanten* (1778), should have been quoted to prove that the method proposed by HERSCHEL in 1782 for ascertaining the parallax of the fixed stars by means of observations of those which were double, was not entirely original with himself.

There is direct proof that it was so,* and if this was not forthcoming it would be un-

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* *Memoir of* CAROLINE HERSCHEL, p. 42.

necessary, as he ~~has amply shown in his~~ Herschel also had

Catalogue of Double Stars. One is reminded of his remarks on the use of the high magnifying powers by the impatience of his comments.

His proposal to call the newly discovered minor planets *asteroids* (1802) was received as a sign that he wished to discriminate between the discoveries of PIAZZI and OLBERS and his own discovery of *Uranus.**

He takes pains to quietly put this on one side in one of his papers, showing that he was cognizant of the existence of such a feeling.]

I am tempted to resurrect from a deserved obscurity a notice of HERSCHEL'S *Observations on the Two Lately Discovered Celestial Bodies*

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* "Of late years these expectations have been more than accomplished by the discovery of no fewer than four planetary bodies, almost all in the same place; but so small that Dr. HERSCHEL refuses to honor them with the name of planets, and chooses to call them asteroids, though for what reason it is not easy to determine, unless it be to deprive the discoverers of these bodies of any pretence for rating themselves as high in the list of astronomical discoverers as himself."—*History of the Royal Society,* by THOMAS THOMSON, p. 358. This work was published in 1812, and therefore during the lifetime of HERSCHEL.

(*Philosophical Transactions*, 1802), printed in the first volume of the *Edinburgh Review*, simply to show the kind of envy to which even he, the glory of England, was subject.

The reviewer sets forth the principal results of HERSCHEL'S observations, and, after quoting his definition of the new term asteroid, goes on to say:

> "If a new name must be found, why not call them by some appellation which shall, in some degree, be descriptive of, or at least consistent with, their properties? Why not, for instance, call them *Concentric Comets*, or *Planetary Comets*, or *Cometary Planets?* or, if a single term must be found, why may we not coin such a phrase as *Planetoid* or *Cometoid?*"

Then follows a general arraignment of HERSCHEL'S methods of expression and thought, as distinguished from his powers of mere observation. This distinction, it may be said, exists only in the reviewer's mind; there was no such distinction in fact. If ever a series of observations was directed by profound and reasonable thought, it was HERSCHEL'S own.

"Dr. HERSCHEL'S passion for coining words and idioms has often struck us as a weakness wholly unworthy of him. The invention of a name is but a poor achievement for him who has discovered whole worlds. Why, for instance, do we hear him talking of the *space-penetrating power* of his instrument—a compound epithet and metaphor which he ought to have left to the poets, who, in some future age, shall acquire glory by celebrating his name. The other papers of Dr. HERSCHEL, in the late volumes of the *Transactions*, do not deserve such particular attention. His catalogue of 500 new nebulæ, though extremely valuable to the practical astronomer, leads to no general conclusions of importance, and abounds with the defects which are peculiar to the Doctor's writings—a great prolixity and tediousness of narration—loose and often unphilosophical reflections, which give no very favorable idea of his scientific powers, however great his merit may be as an observer—above all, that idle fondness for inventing names without any manner of occasion, to which we have already alluded, and a use of novel and affected idioms.

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"To the speculations of the Doctor on the nature of the Sun, we have many similar objections; but they are all eclipsed by the grand absurdity which he has there committed, in his hasty and erroneous theory concerning the influence of the solar spots on the price of grain. Since the publication of Gulliver's voyage to Laputa, nothing so ridiculous has ever been offered to the world.

We heartily wish the Doctor had suppressed it; or, if determined to publish it, that he had detailed it in language less confident and flippant."

One is almost ashamed to give space and currency to a forgotten attack, but it yields a kind of perspective; and it is instructive and perhaps useful to view HERSCHEL'S labors from all sides, even from wrong and envious ones.

The study of the original papers, together with a knowledge of the circumstances in which they were written, will abundantly show that HERSCHEL'S ideas sprung from a profound meditation of the nature of things in themselves. What the origin of trains of thought prosecuted for years may have been we cannot say, nor could he himself have expressed it. A new path in science was to be found out, and he found it. It was not in his closet, surrounded by authorities, but under the open sky, that he meditated the construction of the heavens. As he says, "My situation permitted me not to consult large libraries; nor, indeed, was it very material; for as I intended to view the heavens myself, Nature, that great volume, appeared to me to contain the best catalogue."

His remarkable memoirs on the invisible and other rays of the solar spectrum were received with doubt, and with open denial by many of the scientific bodies of Europe. The reviews and notices of his work in this direction were often quite beyond the bounds of a proper scientific criticism; but HERSCHEL maintained a dignified silence. The discoveries were true, the proofs were open to all, and no response was needed from him. He may have been sorely tempted to reply, but I am apt to believe that the rumors that reached him from abroad and at home did not then affect him as they might have done earlier. He was at his grand climacteric, he had passed his sixty-third year, his temper was less hasty than it had been in his youth, and his nerves had not yet received the severe strain from whose effects he suffered during the last years of his life.

We have some glimpses of his personal

life in the reminiscences of him in the *Diary and Letters* of Madame D'ARBLAY, who knew him well:

"1786.—In the evening Mr. HERSCHEL came to tea. I had once seen that very extraordinary man at Mrs. DE LUC'S, but was happy to see him again, for he has not more fame to awaken curiosity than sense and modesty to gratify it. He is perfectly unassuming, yet openly happy, and happy in the success of those studies which would render a mind less excellently formed presumptuous and arrogant.

"The king has not a happier subject than this man, who owes it wholly to His Majesty that he is not wretched; for such was his eagerness to quit all other pursuits to follow astronomy solely, that he was in danger of ruin, when his talents and great and uncommon genius attracted the king's patronage. He has now not only his pension, which gives him the felicity of devoting all his time to his darling study, but he is indulged in license from the king to make a telescope according to his new ideas and discoveries, that is to have no cost spared in its construction, and is wholly to be paid for by His Majesty.

"This seems to have made him happier even than the pension, as it enables him to put in execution all his wonderful projects, from which his expectations of future discoveries are so sanguine as to make his present existence a state of almost perfect enjoyment. Mr. LOCKE himself would be quite charmed with him.

"He seems a man without a wish that has its object in the terrestrial globe. At night Mr. HERSCHEL, by the king's command, came to exhibit to His Majesty and the royal family the new comet lately discovered by his sister, Miss HERSCHEL ; and while I was playing at piquet with Mrs. SCHWELLENBURG, the Princess AUGUSTA came into the room and asked her if she chose to go into the garden and look at it. She declined the offer, and the princess then made it to me. I was glad to accept it for all sorts of reasons. We found him at his telescope. The comet was very small, and had nothing grand or striking in its appearance ; but it is the first lady's comet, and I was very desirous to see it. Mr. HERSCHEL then showed me some of his new discovered universes, with all the good humor with which he would have taken the same trouble for a brother or a sister astronomer ; there is no possibility of admiring his genius more than his gentleness."

"1786, *December* 30*th.*—This morning my dear father carried me to Dr. HERSCHEL. That great and very extraordinary man received us almost with open arms. He is very fond of my father, who is one of the council of the Royal Society this year, as well as himself. . . . At this time of day there was nothing to see but his instruments ; those, however, are curiosities sufficient. . . . I wished very much to have seen his sister, . . . but she had been up all night, and was then in bed."

"1787, *September.*—Dr. HERSCHEL is a delightful man ;

so unassuming with his great knowledge, so willing to dispense it to the ignorant, and so cheerful and easy in his general manners, that, were he no genius, it would be impossible not to remark him as a pleasing and sensible man."

"1788, *October 3d.*—We returned to Windsor at noon, and Mrs. DE LUC sent me a most pressing invitation to tea and to hear a little music. Two young ladies were to perform at her house in a little concert. Dr. HERSCHEL was there, and accompanied them very sweetly on the violin; his new-married wife was with him, and his sister. His wife seems good-natured; she was rich, too! and astronomers are as able as other men to discern that gold can glitter as well as stars."

DR. BURNEY TO MADAME D'ARBLAY.

"CHELSEA COLLEGE,
"*September* 28, 1798.

"* * * * *

"I drove through Slough in order to ask at Dr. HERSCHEL's door when my visit would be least inconvenient to him—that night or next morning. The good soul was at dinner, but came to the door himself, to press me to alight immediately and partake of his family repast; and this he did so heartily that I could not resist.

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"I expected (not knowing that HERSCHEL was married) only to have found Miss HERSCHEL; but there was a very old lady, the mother, I believe, of Mrs. HERSCHEL, who was at the head of the table herself, and a Scots lady (a Miss WILSON, daughter of Dr. WILSON, of Glasgow, an eminent astronomer), Miss HERSCHEL, and a little boy. They rejoiced at the accident which had brought me there, and hoped I would send my carriage away and take a bed with them. They were sorry they had no stables for my horses.

"We soon grew acquainted—I mean the ladies and I —and before dinner was over we seemed old friends just met after a long absence. Mrs. HERSCHEL is sensible, good-humored, unpretending, and well bred; Miss HERSCHEL all shyness and virgin modesty; the Scots lady sensible and harmless; and the little boy entertaining, promising, and comical. HERSCHEL, you know, and everybody knows, is one of the most pleasing and well-bred natural characters of the present age, as well as the greatest astronomer.

"Your health was drunk after dinner (put that into your pocket), and after much social conversation and a few hearty laughs, the ladies proposed to take a walk, in order, I believe, to leave HERSCHEL and me together. We walked and talked round his great telescopes till it grew damp and dusk, then retreated into his study to philosophize.

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"He made a discovery to me, which, had I known it sooner, would have overset me, and prevented my reading any part of my work.* He said that he had almost always had an aversion to poetry, which he regarded as the arrangement of fine words, without any useful meaning or adherence to truth; but that when truth and science were united to these fine words, he liked poetry very well."

1798, December 10.

DR. BURNEY TO MADAME D'ARBLAY.

"HERSCHEL has been in town for short spurts, and back again two or three times, leaving Mrs. HERSCHEL behind (in town) to transact law business. I had him here two whole days."

The reading of the manuscript of the *Poetical History of Astronomy* was continued, "and HERSCHEL was so humble as to confess that I knew more of the history of astronomy than he did, and had surprised him with the mass of information I had got together.

"He thanked me for the entertainment and instruction I had given him. 'Can anything be grander?' and all this before he knows a word of what I have said of himself—all his discoveries, as you may remember, being kept back for the twelfth and last book."

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* *Poetical History of Astronomy*: this work was nearly completed, but was never published. The whole of it was read to HERSCHEL, in order that BURNEY might have the benefit of his criticism on its technical terms.

DR. BURNEY TO MADAME D'ARBLAY.

"SLOUGH, *Monday morning. July* 22, 1799,
in bed at Dr. HERSCHEL'S, half-past five, where I can neither sleep nor lie idle.

"MY DEAR FANNY:—I believe I told you on Friday that I was going to finish the perusal of my astronomical verses to the great astronomer on Saturday.

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"After tea Dr. HERSCHEL proposed that we two should retire into a quiet room in order to resume the perusal of my work, in which no progress has been made since last December. The evening was finished very cheerfully; and we went to our bowers not much out of humor with each other or the world. . . . After dinner we all agreed to go to the terrace [at Windsor]—Mr., Mrs., and Miss H., with their nice little boy, and three young ladies. Here I met with almost everybody I wished and expected to see previous to the king's arrival.

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"But now here comes Will, and I must get up, and make myself up to go down to the perusal of my last book, entitled *Herschel*. So good-morrow."

"CHELSEA, *Tuesday*.

"Not a moment could I get to write till now. . . . I must tell you that HERSCHEL proposed to me to go with him to the king's concert at night, he having permission to go when he chooses, his five nephews (GRIESBACHS) making a principal part of the band. 'And,' says he, 'I know you will be welcome.'"

An intimacy was gradually established between HERSCHEL and Dr. BURNEY. They saw each other often at the meetings of the Royal Society, and HERSCHEL frequently stayed at the doctor's house. "On the first evening HERSCHEL spent at Chelsea, when I called for my ARGAND lamp, HERSCHEL, who had not seen one of those lamps, was surprised at the great effusion of light, and immediately calculated the difference between that and a single candle, and found it sixteen to one." *

In 1793 we find HERSCHEL as a witness for his friend JAMES WATT, in the celebrated case of WATT *vs.* BULL, which was tried in the Court of Common Pleas. And from MUIRHEAD'S Life of WATT, it appears that HERSCHEL visited WATT at Heathfield in 1810.

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* *Memoirs of* Dr. BURNEY, vol. iii., p. 264.

A delightful picture of the old age of HERSCHEL is given by the poet CAMPBELL,* whose nature was fitted to perceive the beauties of a grand and simple character like HERSCHEL'S:

"[BRIGHTON], *September* 15, 1813.

. . . . "I wish you had been with me the day before yesterday, when you would have joined me, I am sure, deeply in admiring a great, simple, good old man—Dr. HERSCHEL. Do not think me vain, or at least put up with my vanity, in saying that I almost flatter myself I have made him my friend. I have got an invitation, and a pressing one, to go to his house; and the lady who introduced me to him, says he spoke of me as if he would really be happy to see me. . . . I spent all Sunday with him and his family. His son is a prodigy in sciences, and fond of poetry, but very unassuming. . . . Now, for the old astronomer himself. His simplicity, his kindness, his anecdotes, his readiness to explain—and make perfectly conspicuous too—his own sublime conceptions of the universe are indescribably charming. He is seventy-six, but fresh and stout; and there he sat, nearest the door, at his friend's house, alternately smiling at a joke, or contentedly sitting without share or notice in the conversation. Any train of con-

* Life and Letters of THOMAS CAMPBELL, edited by WILLIAM BEATTIE, vol. ii., p. 234.

versation he follows implicitly; anything you ask he labors with a sort of boyish earnestness to explain.

"I was anxious to get from him as many particulars as I could about his interview with BUONAPARTE.* The latter, it was reported, had astonished him by his astronomical knowledge.

"'No,' he said, 'the First Consul did surprise me by his quickness and versatility on all subjects; but in science he seemed to know little more than any well-educated gentleman, and of astronomy much less for instance than our own king. His general air,' he said, 'was something like affecting to know more than he did know.' He was high, and tried to be great with HERSCHEL, I suppose, without success; and 'I remarked,' said the astronomer, 'his hypocrisy in concluding the conversation on astronomy by observing how all these glorious views gave proofs of an Almighty Wisdom.' I asked him if he thought the system of LAPLACE to be quite certain, with regard to the total security of the planetary system from the effects of gravitation losing its present balance? He said, No; he thought by no means that the universe was secured from the chance of sudden losses of parts.

"He was convinced that there had existed a planet between *Mars* and *Jupiter*, in our own system, of which the little asteroids, or planetkins, lately discovered, are indubitably fragments; and 'Remember,' said he, 'that

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* This interview must have taken place in 1802, during HERSCHEL's journey to Paris. We have no other record of it.

though they have discovered only four of those parts, there will be thousands—perhaps thirty thousand more—yet discovered.' This planet he believed to have been lost by explosion.

"With great kindness and patience he referred me, in the course of my attempts to talk with him, to a theorem in NEWTON'S 'Principles of Natural Philosophy' in which the time that the light takes to travel from the sun is proved with a simplicity which requires but a few steps in reasoning. In talking of some inconceivably distant bodies, he introduced the mention of this plain theorem, to remind me that the progress of light could be measured in the one case as well as the other. Then, speaking of himself, he said, with a modesty of manner which quite overcame me, when taken together with the greatness of the assertion: 'I have looked *further into space than ever human being did before me.* I have observed stars, of which the light, it can be proved, must take two millions of years to reach this earth.'

"I really and unfeignedly felt at this moment as if I had been conversing with a supernatural intelligence. 'Nay, more,' said he, 'if those distant bodies had ceased to exist two millions of years ago, we should still see them, as the light would travel after the body was gone. . .' These were HERSCHEL'S words; and if you had heard him speak them, you would not think he was apt to tell more than the truth.

"After leaving HERSCHEL I felt elevated and overcome; and have in writing to you made only this memorandum of some of the most interesting moments of my life."

CAMPBELL'S conscientious biographer appears to have felt that the value of this charming account of his interview with HERSCHEL was in its report of astronomical facts and opinions, and he adds a foot-note to explain that "HERSCHEL'S opinion never amounted to more than *hypothesis* having some degree of probability. Sir JOHN HERSCHEL remembers his father saying, 'If that hypothesis were true, and *if* the planet destroyed were as large as the earth, there must have been at least thirty-thousand such fragments,' but always as an hypothesis—he was never heard to declare any degree of conviction that it was so."

For us, the value of this sympathetic account of a day in HERSCHEL'S life is in its conception of the simplicity, the modesty, the "boyish earnestness," the elevation of thought and speech of the old philosopher; and in the impression made on the feelings, not the mind, of the poet, then thirty-five years old.

In a letter to Alison, Campbell reverts with great pleasure to the day spent with Herschel:

"Sydenham, *December* 12, 1813.

"My dearest Alison :—

* * * * * * *

"I spent three weeks with my family at Brighton, in charming weather, and was much pleased with, as well as benefited by, the place. There I met a man with whom you will stare at the idea of my being congenial, or having the vanity to think myself so—the great Herschel. He is a simple, great being. . . . I once in my life looked at Newton's *Principia*, and attended an astronomical class at Glasgow; wonderful it seemed to myself, that the great man condescended to understand my questions; to become apparently earnest in communicating to me as much information as my limited capacity and preparation for such knowledge would admit. He invited me to see him at his own abode, and so kindly that I could not believe that it was mere good breeding; but a sincere wish to see me again. I had a full day with him; he described to me his whole interview with Buonaparte; said it was not true, as reported, that Buonaparte understood astronomical subjects deeply, but affected more than he knew.

"In speaking of his great and chief telescope, he said with an air, not of the least pride, but with a greatness and simplicity of expression that struck me with wonder, 'I have looked further into space than ever human being did before me. I have observed stars, of which the light takes *two millions* of years to travel to this globe.' I mean to pay him a reverential visit at Slough, as soon as my book is out, this winter."

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In 1807 CAROLINA HERSCHEL has this entry in her diary :

"*October* 4.—My brother came from Brighton. The same night two parties from the Castle came to see the comet, and during the whole month my brother had not an evening to himself. As he was then in the midst of polishing the forty-foot mirror, rest became absolutely necessary after a day spent in that most laborious work ; and it has ever been my opinion that on the 14th of October his nerves received a shock of which he never got the better afterwards."

In the spring of 1808 he was quite seriously ill ; but in May the observing went on again. In 1809 and 1810 his principal investigations were upon physical subjects (NEWTON'S rings), and in 1811 the only long series of observations was upon the comet of that year. After 1811 the state of HERSCHEL'S health required that his observations should be much less frequent. Much of the time after 1811 he was absent, and his work at home consisted largely in arranging the results of his previous labors, and in computations connected with them. All through the years 1814 to 1822, HERSCHEL'S health was very feeble. The severe winter of 1813–14 had told materially upon him. In 1814, however, he undertook to repolish the forty-foot mirror, but was obliged to give it over.

He now found it necessary to make frequent little excursions for change of air and scene. His faithful sister remained at home, bringing order into the masses of manuscript, and copying the papers for the Royal Society.

She was sick at heart, fearing that each time she saw her brother it would be the last. In 1818 she says:

"Feb. 11, I went to my brother and remained with him till the 23d. We spent our time, though not in idleness, in sorrow and sadness. He is not only unwell, but low in spirits."

In 1818 (December 16), HERSCHEL went to London to have his portrait painted by ARTAUD. While he was in London his will was made.*

In 1819 there is a glimmer of the old-time light. In a note HERSCHEL says:

"LINA:—There is a great comet. I want you to assist me. Come to dine and spend the day here. If you can come soon after one o'clock, we shall have time to pre-

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* The will of HERSCHEL was dated December 17th, 1818.

"The personal effects were sworn under £6,000. The copyhold and other lands and tenements at Upton-cum-Chalvey, in the County of Bucks, and at Slough, he decrees to his son, with £25,000 in the 3 per cent. Reduced Annuities. £2,000 are given to his brother JOHANN DIETRICH, and annuities of £100 each to his brother JOHANN ALEXANDER and to his sister CAROLINA; £20 each to his nephews and nieces, and the residue (with the exception of astronomical instruments, telescopes, observations, etc., which he declares to have given, on account of his advanced age, to his son for the purpose of continuing his studies) is left solely to Lady HERSCHEL."—*Gentleman's Magazine*, vol. xcii., 1822, p. 650.

It is not necessary to say here how nobly Sir JOHN HERSCHEL redeemed the trust confided in him. All the world knows of his Survey of the Southern Heavens, in which he completed the review of the sky which had been begun and completed for the northern heavens by the same instruments in his father's hands. A glance at the Bibliography at the end of this book will show the titles of several papers by Sir JOHN, written with the sole object of rendering his father's labors more complete.

pare maps and telescopes. I saw its situation last night. It has a long tail.

"*July* 4, 1819."

This note has been carefully kept by his sister, and on it she has written: "I keep this as a relic. Every line *now* traced by the hand of my dear brother becomes a treasure to me."

So the next three years passed away. Sir WILLIAM * was daily more and more feeble. He spent his time in putting his works in order, but could devote only a few moments each day to this. His sister says:

"*Aug.* 11*th*, 12*th*, 13*th*, and 14*th* [1822], I went as usual to spend some hours of the forenoon with my brother.

"*Aug.* 15*th*.—I hastened to the spot where I was wont to find him, with the newspaper which I was to read to him. But instead I found Mrs. MONSON, Miss BALDWIN, and Mr. BULMAN, from Leeds, the grandson of my brother's earliest acquaintance in this country. I was informed my brother had been obliged to return to his room, whither I flew immediately. Lady H. and the housekeeper were with him, administering everything

* He was created a knight of the Royal Hanoverian Guelphic Order in 1816, and was the first President of the Royal Astronomical Society in 1821, his son being its first Foreign Secretary.

which could be thought of for supporting him. I found him much irritated at not being able to grant Mr. BULMAN's request for some token of remembrance for his father. As soon as he saw me, I was sent to the library to fetch one of his last papers and a plate of the forty-foot telescope. But for the universe I could not have looked twice at what I had snatched from the shelf, and when he faintly asked if the breaking up of the Milky Way was in it, I said 'Yes,' and he looked content. I cannot help remembering this circumstance; it was the last time I was sent to the library on such an occasion. That the anxious care for his papers and workrooms never ended but with his life, was proved by his frequent whispered inquiries if they were locked and the key safe, of which I took care to assure him that they were, and the key in Lady HERSCHEL's hands.

"After half an hour's vain attempt to support himself, my brother was obliged to consent to be put to bed, leaving no hope ever to see him rise again."

On the 25th of August, 1822, HERSCHEL died peacefully at the age of eighty-four years.

His remains lie in the little church at Upton, near Windsor, where a memorial tablet has been erected by his son. The epitaph is as follows: *

* BODE's *Jahrbuch*, 1823, p. 222.

H. S. E.

GULIELMUS HERSCHEL Eques Guelphicus
Hanoviæ natus Angliam elegit patriam
Astronomis ætatis suæ præstantissimis
Merito annumeratus
Ut leviora sileantur inventa
Planetam ille extra Saturni orbitam
Primus detexit
Novis artis adjumentis innixus
Quæ ipse excogitavit et perfecit
Cœlorum perrupit claustra
Et remotiora penetrans et explorans spatia
Incognitos astrorum ignes
Astronomorum oculis et intellectui subjecit
Qua sedulitate qua solertia
Corporum et phantasmatum
Extra systematis nostri fines lucentium
Naturam indagaverit
Quidquid paulo audacius conjecit
Ingenita temperans verecundia
Ultro testantur hodie æquales
Vera esse quæ docuit pleraque
Siquidem certiora futuris ingeniis subsidia
Debitura est astronomia
Agnoscent forte posteri
Vitam utilem innocuam amabilem
Non minus felici laborum exitu quam virtutibus
Ornatam et vere eximiam
Morte suis et bonis omnibus deflenda
Nec tamen immatura clausit
Die XXV Augusti A. D. CIƆIƆCCCXXII
Ætatis vero suæ LXXXIV.

CHAPTER IV.

REVIEW OF THE SCIENTIFIC LABORS OF WILLIAM HERSCHEL.

In this chapter I shall endeavor to give such explanations as will enable the general reader to follow the course of discovery in each branch of astronomy and physics, regularly through the period of Herschel's life, and up to the state in which he left it.

A more detailed and precise account, which should appeal directly to the professional astronomer, will not be needed, since Arago has already fulfilled this want in his "*Analyse de la vie et des travaux de Sir William Herschel*," published in 1842. The few misconceptions there contained will be easily corrected by those to whom alone they are of consequence. The latter class of readers may also consult the abstracts of HERSCHEL'S memoirs, which have been given in "*A Subject-index and a Synopsis of the Scientific Writings of Sir WILLIAM HERSCHEL,*" prepared by Dr. HASTINGS and myself, and published by the Smithsonian Institution.

An accurate sketch of the state of astronomy in England and on the Continent, in the years 1780–1820, need not be given. It will be enough if we remember that of the chief observatories of Europe, public and private, no one was actively devoted to such labors as were undertaken by HERSCHEL at the very beginning of his career.

His observations on variable stars, indeed, were in the same line as those of PIGOTT; FLAUGERGUES and DARQUIER, in France, had perhaps preceded him in minute scrutiny of the sun's surface, etc.; but, even in that department of observation, he at once put an immense distance between himself and others by the rapid and extraordinary advances in the size and in the excellence of his telescopes. Before his time the principal aids to observation were the Gregorian and Newtonian telescopes of SHORT, and the small achromatics of DOLLOND.*

We have seen, in what goes before, how his patient zeal had succeeded in improving upon these. There was no delay, and no rest. Steadily the art of making reflectors was urged forward, until he had finally in his hands the forty-foot telescope.

It must be admitted that this was the limit to which the manufacture of powerful telescopes could be pushed in his generation. The optical and mechanical difficulties which prevented a farther advance required time for their solution; and, indeed, some of these difficulties are scarcely solved at this day. It may fairly be said that no reflector larger than three feet in aperture has yet realized our expectations.

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* JAMES SHORT, F.R.S. (1710–1768), and JOHN DOLLOND, F.R.S. (1706–1761), were the most celebrated makers of telescopes of their day. The six-foot Newtonian reflectors of SHORT (aperture 9.4 inches), and the forty-six-inch achromatics of DOLLOND (aperture 3.6 inches), were highly esteemed. The Royal Observatory of Greenwich possessed, in 1765, one of each class. In a comparative trial of SHORT's telescope, at Greenwich, and one of HERSCHEL's first telescopes, the latter was adjudged greatly superior.

The Improvement of Telescopes and Optical Apparatus.

It will be of interest to give in this place some connected account of the large forty-foot reflector, of four feet aperture, made by HERSCHEL. Its history extends from 1785 to 1811. Its manufacture was considered by his cotemporaries as his greatest triumph. As a machine, it was extremely ingenious in all its parts, as may be seen from the elaborate description and plates of it published in the *Philosophical Transactions* for 1795. One of its mirrors certainly had good definition, for, by means of it, the two small satellites of *Saturn* (*Mimas* and *Enceladus*) were discovered, and these discoveries alone would make it famous. Perhaps more was expected of it by the public in general than it absolutely performed. Its merits were after a while decried, and HERSCHEL even felt obliged to state why he did not always employ it in his observations. His reasons were perfectly valid, and such as any one may understand. The time required to get so large a machine into working order was a serious tax; it required more assistants than his twenty-foot telescope, and he says, "I have made it a rule never to employ a larger telescope when a smaller will answer the purpose."

It still remains as a remarkable feat of engineering and an example of great optical and mechanical skill. It led the way to the large reflectors of Lord Rosse, some sixty years later, and several of the forty-foot telescopes of the present day even have done less useful work. Its great feat, however, was to have added two satellites to the solar system. From the published accounts of it the following is taken:

"When I resided at Bath I had long been acquainted with the theory of optics and mechanics, and wanted only that experience so necessary in the practical part of these sciences. This I acquired by degrees at that place, where in my leisure hours, by way of amusement, I made several two-foot, five-foot, seven-foot, ten-foot, and twenty-foot Newtonian telescopes, beside others, of the Gregorian form, of eight, twelve, and eighteen inches, and two, three, five, and ten feet focal length. In this way I made not less than two hundred seven-foot, one hundred and fifty ten-foot, and about eighty twenty-foot mirrors, not to mention the Gregorian telescopes.*

"The number of stands I invented for these telescopes it would not be easy to assign. . . . In 1781 I began to construct a thirty-foot aërial reflector, and having made a stand for it, I cast the mirror thirty-six inches in diameter. This was cracked in cooling. I cast it a second time, and the furnace I had built in my house broke."

Soon after, the Georgian planet was discovered, and this interrupted the work for a time.

"In the year 1783 I finished a very good twenty-foot reflector with a large aperture, and mounted it upon the plan of my present telescope. After two years' observation with it, the great advantage of such apertures appeared so clearly to me that I recurred to my former intention of increasing them still further; and being now sufficiently provided with experience in the work which I wished to undertake, the President of the Royal Society, who is always ready to promote useful undertakings, had the goodness to lay my design before the king. His Majesty was graciously pleased to approve of it, and with his usual liberality to support it with his royal bounty.

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* At least *one* of these telescopes had the principal mirror made of glass instead of metal.—*Philosophical Transactions*, 1803.

"In consequence of this arrangement I began to construct the forty-foot telescope about the latter end of 1785.* The woodwork of the stand and machines for giving the required motions to the instrument were immediately put in hand. In the whole of the apparatus none but common workmen were employed, for I made drawings of every part of it, by which it was easy to execute the work, as I constantly inspected and directed every person's labor; though sometimes there were not less than forty different workmen employed at the same time. While the stand of the telescope was preparing, I also began the construction of the great mirror, of which I inspected the casting, grinding, and polishing, and the work was in this manner carried on with no other interruption than that occasioned by the removal of all the apparatus and materials from where I then lived, to my present situation at Slough.

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* The following extract from FOURIER's *Éloge* of HERSCHEL is of interest in this connection. The sum first appropriated by the king was £2,000. This was afterwards raised to £4,000, and a sum of £200 yearly was given for maintenance.

"L'histoire doit conserver à jamais la réponse de ce prince à un étranger célèbre [LALANDE ?] qui le remerciait des sommes considérables accordées pour les progrès de l'astronomie. 'Je fais les dépenses de la guerre,' dit le roi, 'parcequ'elles sont nécessaires; quant à celles des sciences, il m'est agréable des les ordonner; leur objet ne coûte point des larmes, et honore l'humanité.'"

LALANDE's own account is a little different. He says the king exclaimed: "Ne vaut-il pas mieux employer son argent à cela qu'à faire tuer des hommes?"

"Here, soon after my arrival, I began to lay the foundation upon which by degrees the whole structure was raised as it now stands, and the speculum being highly polished and put into the tube, I had the first view through it on February 19, 1787. I do not, however, date the completing of the instrument till much later. For the first speculum, by a mismanagement of the person who cast it, came out thinner on the centre of the back than was intended, and on account of its weakness would not permit a good figure to be given to it.

"A second mirror was cast January 26, 1788, but it cracked in cooling. February 16 we recast it, and it proved to be of a proper degree of strength. October 24 it was brought to a pretty good figure and polish, and I observed the planet *Saturn* with it. But not being satisfied, I continued to work upon it till August 27, 1789, when it was tried upon the fixed stars, and I found it to give a pretty sharp image. Large stars were a little affected with scattered light, owing to many remaining scratches on the mirror. August the 28th, 1789, having brought the telescope to the parallel of *Saturn*, I discovered a *sixth* satellite of that planet, and also saw the spots upon *Saturn* better than I had ever seen them before, so that I may date the finishing of the forty-foot telescope from that time."

Another satellite of *Saturn* was discovered with the forty-foot on the 17th of September (1789). It was used for various observations so late as 1811. On January 19, of that year, HERSCHEL observed the nebula of *Orion* with it. This was one of his last observations.

The final disposition of the telescope is told in the following extract from a letter of Sir JOHN HERSCHEL'S to Mr. WELD, Secretary of the Royal Society:

"COLLINGWOOD, *March* 13, 1847.

. . . "In reply to your queries, respecting the forty-foot reflecting telescope constructed by my father, I have to state that King GEORGE III. munificently defrayed the *entire* cost of that instrument (including, of course, all preparatory cost in the nature of construction of tools, and of the apparatus for casting, grinding, and figuring the reflectors, of which two were constructed), at a total cost of £4,000. The woodwork of the telescope being so far decayed as to be dangerous, in the year 1839 I pulled it down, and piers were erected on which the tube was placed, *that* being of iron and so well preserved, that, although not more than one-twentieth of an inch thick, when in the horizontal position it sustained within it all my family, and continues to sustain inclosed within it, to this day, not only the heavier of the two reflectors, but also all the more important portions of the machinery. . . . The other mirror and the rest of the polishing apparatus are on the premises. The iron grinding tools and polishers are placed underneath the tube, let into the ground, and level with the surface of the gravelled area in which it stands." . . .

The closing of the tube was done with appropriate ceremony on New-Year's-Day, 1840, when, after a procession through it by the family at Slough, a poem, written by Sir JOHN, was read, the machinery put into its present position, and the tube sealed.

The memoir on the forty-foot telescope shows throughout that HERSCHEL'S prime object was not the making of the telescope itself, but that his mind was constantly directed towards the uses to which it was to be put—towards the questions which he wished it to answer.

Again and again, in his various papers, he returns to the question of the *limit of vision.* As BESSEL has said:

"The naked eye has its limit of vision in the stars of the sixth magnitude. The light of fainter stars than these does not affect the retina enough for them to be seen. A very small telescope penetrates to smaller, and, in general, without doubt, to more distant stars. A more powerful one penetrates deeper into space, and as its power is increased, so the boundaries of the visible universe are widened, and the number of stars increased to millions and millions. Whoever has followed the history of the series of HERSCHEL's telescopes will have observed this. But HERSCHEL was not content with the bare fact, but strove ever to know *how far* a telescope of a certain construction and size could penetrate, compared with the naked and unassisted eye. These investigations were never for the discovery of new facts concerning the working of his instruments; it was for the knowledge of the distribution of the fixed stars in space itself that he strove. . . . HERSCHEL's instruments were designed to aid vision to the last extent. They were only secondarily for the taking of measures. His efforts were not for a knowledge of the *motions*, but of the *constitution* and *construction* of the heavenly bodies."

Besides the stands for his telescopes, which were both ingenious and convenient, HERSCHEL devised many forms of apparatus for facilitating the art of observation. His micrometers for measuring position angles, his lamp micrometer, the method of limiting apertures, and the methods he used for viewing the sun may be mentioned among these.

Points in practical astronomy are considered all through the years of observation.

A reference to his original papers will show how numerous, how varied, and how valuable these are. I cannot forbear quoting here the account of a precaution observed during his examination of the belts on *Saturn* (1794).

It is the most striking example of how fully HERSCHEL realized that the eye of the observer is a material part of the optical apparatus of astronomy. Simple as this principle may appear, it was an absolute novelty in his day.

In making these observations, he says :

"I took care to bend my head so as to receive the picture of the belt in the same direction as I did formerly. This was a precaution that occurred to me, as there was a possibility that the vertical diameter of the retina might be more or less sensitive than the horizontal one."

Astronomers will recognize in this the first suggestion of the processes which have led to important results in the hands of Dr. OTTO STRUVE and others in the comparison of the measures of double stars by different observers, each of whom has a personal habit of observation, which, if not corrected, may affect his results in the way which HERSCHEL was striving to avoid.

Researches on the Relative Brightness of the Stars: Variable Stars.

No research of HERSCHEL's was more laborious than the elaborate classification of the stars according to their comparative brightness, which he executed during the years 1796 to 1799. It was directly in the line of his main work—to find out the construction of the heavens.

His first paper had been upon the variable star *Mira Ceti.* Here was a sun, shining by its native brightness, which waxed and waned like the moon itself. This star is periodic. It is for a long period invisible to the unassisted eye. Then it can just be seen, and increases in brightness for a little over a month, and attains a maximum brilliancy. From this it decreases for nearly three months, and after becoming invisible, remains so for five or six months. Its whole period is about 333 days. Are all other stars constant in brightness?

The example of *Mira Ceti* and of other known variables makes this at least doubtful. But the sun itself may vary for all that we know. It is a simple star like the rest.

This question of variability in general is an important one, then. It can only be tested by making accurate catalogues of the relative brilliance of stars at various times, and by comparing these. No such general catalogue existed before HERSCHEL's time, and led by the discrepancies in isolated cases, which he found between his own estimates and those of his predecessors, he made from observation a series of four catalogues, in which were set down the order of sequence of the stars of each constellation.

The method adopted by HERSCHEL was perfectly simple in principle, though most laborious in practice. Suppose any number of stars, A, B, C, D, E, . . . etc., near enough to each other to be well compared. The process consists simply in writing down the names of the stars, A, B, C, etc., in the order of their relative brightness. Thus if for a group of eight stars we have found at one epoch A, B, C, D, E, F, G, H, and if at another time the order was A, B, C, D, F, E, G, H, symptoms of variability are pointed out. Repeated observations, where the same star is found in different sequences, will decide the question. Thus, for the stars visible to the naked eye, we know exactly the state of the sky in HERSCHEL's day, now nearly a century ago. Any material change cannot escape us. These catalogues have been singularly overlooked by the observers of our generation who have followed this branch of observation, and it was not till 1876 that they received proper attention and a suitable reduction (at the hands of Mr. C. S. PIERCE).

We owe to HERSCHEL the first trustworthy account of the stars visible to the naked eye, and since the date of his labors (about 1800) we have similar views published by ARGELANDER (1839), HEIS (1848), ARGELANDER and SCHÖNFELD (1857), GOULD (1860 and 1872), and HOUZEAU (1875). Thus his labors have been well followed up.

In the prosecution of this work HERSCHEL found stars whose light was progressively diminishing, others which regularly increased, one star whose light periodically varies (*α Herculis*), and at least one star (55 *Herculis*) which has utterly disappeared. On October 10, 1781, and April 11, 1782, he observed this latter star, but in May, 1791, it had totally vanished. There was no trace remaining.

The discovery of the variability of *α Herculis* was a more important one than would at first sight appear. Up to that time the only variable stars known were seven in number. Their periods were four hundred and ninety-four, four hundred and four, three hundred and thirty-four, seven, six, five, and three days. These periods seemed to fall into two groups, one of from three hundred to five hundred days, the other comparatively much shorter, of three to seven days. *α Herculis* came to occupy the middle place between these groups, its period being about sixty days.

The cause of these strange and regular variations of brightness was supposed by HERSCHEL to be the rotation of the star bodily on an axis, by which revolution different parts of its surface, of different brilliancy, were successively and periodically presented to us. This explanation it might have been difficult to receive, when the periods of the known variables were so markedly various in length. His own discovery came to bridge over the interval, and quite confirmed him in his belief. He returned to the subject of the revolution of stars about their axes again and again, and connected it with the revolution of satellites.

He found that the satellites of *Jupiter* and one of *Saturn's* periodically changed in brightness, and by quite simple means showed that their periods of rotation were at least approximately the same as their periods of revolution about their primaries. In this case, as in every other, he considered a discovery in each and every one of its possible bearings. There are no instances where he has singularly overlooked the consequences of his observations.

Researches on Double Stars.

The double stars were the subject of HERSCHEL'S earliest and of his latest papers. In

1782 he published his "*Catalogue of Double Stars,*" and his last published memoir (1822) was on the same subject.

The question of determining the parallax of stars first brought HERSCHEL to the discovery of double stars. If two stars, A and B, appear very close together, and if, in reality, the star B is very many times more distant from the earth than A, although seen along the same line of sight, then the revolution of the earth in its orbit will produce changes in the relative situation of A and B, and, in fact, B will describe a small orbit about A, due to this revolution. This idea had been proposed by GALILEO, and measures on this plan had been made by LONG, with negative results. But HERSCHEL, in reviewing their work, declares that the stars chosen by LONG were not suitable to the purpose. It is necessary, among other things, to the success of this method, that it should be certain that the star B is really very much more distant than the star A. The only general test of the distance of stars is their brilliancy, and HERSCHEL decided to use only stars for this research which had two components very greatly different in brightness. A must be very bright (and presumably near to us), and B must be very close to A, and very faint (and thus, presumably, very distant).

It was in the search for such pairs of stars that the *Catalogue of Double Stars* (1782) was formed. HERSCHEL'S first idea of a double star made such pairs as he found, to consist of two stars *accidentally* near to each other. A was near to us, and appeared projected in a certain place on the celestial sphere. B was many times more distant, but, by chance, was seen along the same line, and made with A an *optical* double. If the two stars were at the same distance from the earth, if they made part of the same physical system, if one revolved around the other, then this method of gaining a knowledge of their distance failed. Even in his first memoir on the subject, a surmise that this latter state might occur in some cases, was expressed by HERSCHEL. The notes on some of the pairs declare that a motion of one of them was suspected. But this motion might be truly orbital—of one star about the other as a centre—or it might simply be that one star was moving by its own *proper* motion, and leaving the other behind. It was best to wait and see. The first Catalogue of Double Stars contained two hundred and three instances of such associations. These were observed from time to time, and new pairs discovered. The paper of MICHELL, "An Inquiry into the probable Parallax and Magnitude of the Fixed Stars, from the Quantity of Light which they Afford, and the Particular Circumstances of their Situation" (1767), was read and pondered. By 1802 HERSCHEL had become certain that there existed in the heavens real pairs of stars, both at the same distance from the earth, which were physically connected with each other. The arguments of MICHELL have been applied by BESSEL to the case of one of HERSCHEL's double stars, in much the same order in which the argument ran in HERSCHEL's own mind, as follows:

The star *Castor* (*α Geminorum*) is a double star, where A is of the second, and B of the fourth, magnitude. To the naked eye these two appear as one star. With a telescope this is seen to be two stars, some 5″ apart. In the whole sky there are not above fifty such stars as the brighter of the two, and about four hundred of the brilliancy of B. These fifty and four hundred stars are scattered over the vault of heaven, almost at random. No law has yet been traced by which we can say that here or here there shall be a bright star like A, or a fainter one like B. In general the distribution appears to be fortuitous. How then can we account for one of the four hundred stars like B placed so close to one of the fifty like A?

The chances are over four hundred thousand to one that the association in position is not accidental. This argument becomes overwhelming when the same association is found in many other cases. There were two hundred and three doubles in the Catalogue of 1782 alone, and many thousands are now known.

By a process like this, HERSCHEL reached his grand discovery of true binary systems, where one sun revolves about another. For he saw that if the two stars are near together in space, they could not stand still in face of each other, but that they must revolve in true orbits. Here was the discovery which came to take the place of the detection of the parallaxes of the fixed stars.

He had failed in one research, but he was led to grand conclusions. Was the force that these distant pairs of suns obeyed, the force of gravitation? This he could not settle, but his successors have done so. It was not till about 1827 that SAVARY, of the Paris Observatory, showed that one of HERSCHEL's doubles was subjected to the law of gravitation, and thus extended the power of this law from our system to the universe at large. HERSCHEL himself lived to see some of his double stars perform half a revolution.

Of HERSCHEL's discoveries, ARAGO thinks this has "le plus d'avenir." It may well be so. The laws which govern our solar system have been extended, through his researches, to regions of unknown distance. The binary stars will afford the largest field for research into the laws which govern them, and together with the clusters and groups, they will give a firm basis by which to study the distribution of stars in general, since here we have the great advantage of knowing, if not the real distance of the two stars from the earth, at least that this distance is alike for both.]

Researches on Planets and Satellites.

After HERSCHEL'S first publication on the mountains of the Moon (1780), our satellite appears to have occupied him but little. The observation of volcanoes (1787) and of a lunar eclipse are his only published ones. The planets *Mercury*, *Venus*, *Mars*, and *Jupiter*, although they were often studied, were not the subjects of his more important memoirs. The planet *Saturn*, on the contrary, seems never to have been lost sight of from the time of his first view of it in 1772.

The field of discovery always appears to be completely occupied until the advent of a great man, who, even by his way of putting old and familiar facts, shows the paths along which discoveries must come, if at all. This faculty comes from profound reflection on the nature of the subject itself, from a sort of transmuting power which changes the words of the books into the things of reality. HERSCHEL's paper on *Saturn*, in 1790, is an admirable example of this.

HERSCHEL's observations on *Saturn* began in 1772. From 1790 to 1808 he published six memoirs on the figure, the ring, and the satellites of this planet. The spheroidal shape of the ball was first discovered by him, and we owe much of our certain knowledge of the constitution of the rings to his work. The sixth and seventh satellites, *Mimas* and *Enceladus*, were discovered by him in 1789. The periods of rotation of the ball and of the ring were also fixed. In his conclusions as to the real figure of the rings, there is a degree of scientific caution which is truly remarkable, and which to-day seems almost excessive.

In his paper of 1792, HERSCHEL shows that the most distant satellite of *Saturn*—*Japetus*—turns once on its axis in each revolution about its primary, just as our moon does. He says of this:—

"I cannot help reflecting with some pleasure on the discovery of an analogy which shows that a certain uniform plan is carried on among the secondary planets of our solar system; and we may conjecture that probably most of the satellites are governed by the same law; especially if it be founded on such a construction of their figure as makes them more ponderous towards their primary planets."

I believe the last suggestion to have been the first statement of the possible arrangement of matter in satellites, which was afterwards so forcibly maintained by HANSEN in his theory of the moon. HANSEN's researches show the consequences of such an arrangement, although they do not prove its existence.

It should be recorded that the explanation which is to-day received of the belts and bands upon *Jupiter*, is, I believe, first found in HERSCHEL's memoir on *Venus* (1793). His memoir of 1797, on the changeable brightness of the satellites of *Jupiter*, has already been referred to. The times of the rotation of the satellites on their axes was first determined by HERSCHEL from these observations, which also contain accounts of the curious, and as yet unexplained, phenomena attending their appearances on the disc of the planet.

HERSCHEL discovered in January, 1787, the two brighter satellites of *Uranus*, now called *Oberon* and *Titania*. They are among the faintest objects in the solar system. A later discussion of all his observations led him to the belief that there were four more, and he gives his observations and computations in full. He says that of the existence of additional satellites he has no doubt. Of these four, three were exterior to the most distant satellite *Oberon*, the other was "interior" to *Titania*.

It was not until 1834 that even *Oberon* and *Titania* were again observed (by Sir JOHN HERSCHEL) with a telescope of twenty feet, similar to that which had discovered them, and not until 1847 was the true state of this system known, when Mr. LASSELL discovered *Ariel* and *Umbriel*, two satellites interior to *Titania*, neither of which was HERSCHEL'S "interior" satellite. In 1848 and later years Mr. LASSELL, by the aid of telescopes constructed by himself, fully settled the fact that only four satellites of this planet existed. In 1874 I examined the observations of HERSCHEL on his supposed "interior" satellite, thinking that it might be possible that among the very few glimpses of it which he recorded, some might have belonged to *Ariel* and some to *Umbriel*, and that by combining rare and almost accidental observations of two satellites which really existed, he had come to announce the existence of an "interior" satellite which had no existence in fact. Such I believe to be the case. In 1801, April 17, HERSCHEL describes an interior satellite in the position angle 189°, distant 18″ from the planet. At that instant *Umbriel*, one of Mr. LASSELL's satellites, was in the position 191°, and distant 21″ from *Uranus*, in the most favorable position for seeing it. The observation of 1794, March 27, *may* belong to *Ariel*. At the best the investigation is of passing interest only, and has nothing to do with the question of the discovery of the satellites. HERSCHEL discovered the two brighter ones, and it was only sixty years later that they were properly re-observed by Mr. LASSELL, who has the great honor of having added as many more, and who first settled the vexed question of satellites *exterior* to *Oberon*, and this with a reflecting telescope made by himself, which is unequalled by any other of its dimensions.

Researches on the Nature of the Sun.

In the introduction to his paper on the *Nature and Construction of the Sun and Fixed Stars* (1795), HERSCHEL recounts what was known of the nature of the sun at that time. NEWTON had shown that it was the centre of the system; GALILEO and his successors had determined its rotation, the place of its equator, its real diameter, magnitude, density, distance, and the force of gravity on its surface. He says:

"I should not wonder if, considering all this, we were induced to think that nothing remained to be added; and yet we are still very ignorant in regard to the internal construction of the sun." "The spots have been supposed to be solid bodies, the smoke of volcanoes, the scum floating on an ocean of fluid matter, clouds, opaque masses, and to be many other things." "The sun itself has been called a globe of fire, though, perhaps, metaphorically." "It is time now to profit by the observations we are in possession of. I have availed myself of the labors of preceding astronomers, but have been induced thereto by my own actual observation of the solar phenomena."

HERSCHEL then refers to the theories advanced by his friend, Prof. WILSON, of Glasgow, in 1774. WILSON maintained that the spots were depressions below the sun's atmosphere, vast hollows as it were, at the bases of which the true surface of the sun could be seen.

The essence of his theory was the existence of two different kinds of matter in the sun: one solid and non-luminous—the nucleus—the other gaseous and incandescent—the atmosphere. Vacant places in the atmosphere, however caused, would show the black surface of the solid mass below. These were the spots. No explanation could be given of the *faculæ*, bright streaks, which appear on the sun's surface from time to time; but his theory accounted for the existence of the black *nuclei* of the spots, and for the existence of the *penumbræ* about these. The penumbra of a spot was formed by the thinner parts of the atmosphere about the vacancy which surrounded the nucleus.

This theory of WILSON's was adopted by HERSCHEL as a basis for his own, and he brought numerous observations to confirm it, in the modified shape which he gave to it.

According to HERSCHEL, the sun consisted of three essentially different parts. First, there was a solid nucleus, non-luminous, cool, and even capable of being inhabited. Second, above this was an atmosphere proper; and, lastly, outside of this was a layer in which floated the clouds, or bodies which gave to the solar surface its intense brilliancy:

"According to my theory, a dark spot in the sun is a place in its atmosphere which happens to be free from luminous decompositions" above it.

The two atmospheric layers, which will be of varying thickness about a spot, will account for all the shades of darkness seen in the penumbra. Ascending currents from the solar surface will elevate certain regions, and may increase the solar activity near by, and will thus give rise to faculæ, which HERSCHEL shows to be elevated above the general surface. It will not be necessary to give a further account of this theory. The data in the possession of the modern theorist is a thousand-fold that to be derived from HERSCHEL's observations, and, while the subject of the internal construction of the sun is to-day unsettled, we know that many important, even fundamental, portions of his theory are untenable. A remark of his should be recorded, however, as it has played a great part in such theories:

"That the emission of light must waste the sun, is not a difficulty that can be opposed to our hypothesis. Many of the operations of Nature are carried on in her great laboratory which we cannot comprehend. Perhaps the many telescopic comets may restore to the sun what is lost by the emission of light."

Arguments in favor of the habitability of both sun and moon are contained in this paper; but they rest more on a metaphysical than a scientific basis, and are to-day justly forgotten.

Researches on the Motion of the Sun and of the Solar System in Space.

In 1782 HERSCHEL writes, in regard to some of his discoveries of double stars:

> "These may serve another very important end. I will just mention it, though it is foreign to my present purpose. Several stars of the first magnitude have been observed or suspected to have a proper motion; hence we may surmise that our sun, with all its planets and comets, may also have a motion towards some particular point of the heavens. . . . If this surmise should have any foundation, it will show itself in a series of some years in a kind of systematical parallax, or change, due to the motion of the whole solar system."

In 1783 he published his paper *On the Proper Motion of the Solar System,* which contained the proofs of his surmises of a year before. That certain of the stars had in fact a *proper* motion had been well established by the astronomers of the eighteenth century.

After all allowances had been made for the effects of precession and other displacements of a star's position which were produced by motions of the earth, it was found that there were still small outstanding differences which must be due to the motion of the star itself—its proper motion. The quantity of this motion was not well known for any star when HERSCHEL's researches began. Before they were concluded, however, MASKELYNE had deduced the proper motions of thirty-six stars—the fundamental stars, so called—which included in their number *Sirius*, *Procyon*, *Arcturus*, and generally the brightest stars.

It is *à priori* evident that stars, in general, must have proper motions, when once we admit the universality of gravitation. That any fixed star should be entirely at rest would require that the attractions on all sides of it should be exactly balanced. Any change in the position of this star would break up this balance, and thus, in general, it follows that stars must be in motion, since all of them cannot occupy such a critical position as has to be assumed. If but one fixed star is in motion, this affects all the rest, and we cannot doubt but that every star, our sun included, is in motion by an amount which varies from small to great. If the sun alone had a motion, and the other stars were at rest, the consequence of this would be that all the fixed stars would appear to be retreating *en masse* from that point in the sky towards which we were moving. Those nearest us would move more rapidly, those more distant less so. And in the same way, the stars from which the solar system was receding would seem to be approaching each other. If the stars, instead of being quite at rest, as just supposed, had motions proper to themselves, then we should have a double complexity. They would still appear to an observer in the solar system to have motions, and part of these motions would be truly proper to the stars, and part would be due to the advance of the sun itself in space.

Observations can show us only the *resultant* of these two motions. It is for reasoning to separate this resultant into its two components. At first the question is to determine whether the results of observation indicate any solar motion at all. If there is none, the proper motions of stars will be directed along all possible lines. If the sun does truly move, then there will be a general agreement in the resultant motions of the stars near the ends of the line along which it moves, while those at the sides, so to speak, will show comparatively less systematic effect. It is as if one were riding in the rear of a railway train and watching the rails over which it has just passed. As we recede from any point, the rails at that point seem to come nearer and nearer together.

If we were passing through a forest, we should see the trunks of the trees from which we were going apparently come nearer and nearer together, while those on the sides of us would remain at their constant distance, and those in front would grow further and further apart.

These phenomena, which occur in a case where we are sensible of our own motion, serve to show how we may deduce a motion, otherwise unknown, from the appearances which are presented by the stars in space.

In this way, acting upon suggestions which had been thrown out previously to his own time by LAMBERT, MAYER, and BRADLEY, HERSCHEL demonstrated that the sun, together with all its system, was moving through space in an unknown and majestic orbit of its own. The centre round which this motion is directed cannot yet be assigned. We can only know the point in the heavens towards which our course is directed—" the apex of solar motion."

By a study of the proper motions assigned by MASKELYNE to the brighter stars, HERSCHEL was able to define the position of the solar apex with an astonishing degree of accuracy. His calculations have been several times repeated with the advantage of modern analytical methods, and of the hundred-fold material now at our disposition, but nothing essential has been added to his results of 1805, which were based upon such scanty data; and his paper of 1782 contains the announcement of the discovery itself.

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His second paper on the *Direction* and *Velocity* of the solar system (1805) is the best example that can possibly be given of his marvellous skill in reaching the heart of a matter, and it may be the one in which his philosophical powers appear in their highest exercise. For sustained reflection and high philosophic thought it is to be ranked with the researches of NEWTON in the *Principia*.

Researches on the Construction of the Heavens.

HERSCHEL'S papers on the Construction of the Heavens, as he named it, extended over his whole scientific life. By this he specially means the method according to which the stars, the clusters, the nebulæ, are spread through the regions of space, the causes that have led to this distribution, and the laws to which it is subjected.

No single astronomical fact is unimportant in the light which it may throw on the scheme of the whole, and each fact is to be considered in this light. As an instance: his discovery of the variable star *α Hercu-*

lis, which has a period of sixty days, was valuable in itself as adding one more to the number of those strange suns whose light is now brighter, now fainter, in a regular and periodic order. But the chief value of the discovery was that now we had an instance of a periodic star which went through all its phases in sixty days, and connected, as it were, the stars of short periods (three to seven days) with those of very long ones (three hundred to five hundred days), which two groups had, until then, been the only ones known. In the same way all his researches on the parallaxes of stars were not alone for the discovery of the distance of any one or two single stars, but to gain a unit of celestial measure, by means of which the depths of space might be sounded.

Astronomy in HERSCHEL'S day considered the bodies of the solar system as separated from each other by distances, and as filling a cubical space. The ideas of near and far, of up and down, were preserved, in regard to them, by common astronomical terms. But the vast number of stars seemed to be thought of, as they appear in fact to exist, lying on the surface of a hollow sphere. The immediate followers of BRADLEY used these fixed stars as points of reference by which the motions within the solar system could be determined, or, like LACAILLE and LALANDE, gathered those immense catalogues of their positions which are so indispensable to the science. MICHELL and HERSCHEL alone, in England, occupied their thoughts with the nature and construction of the heavens—the one in his study, the other through observation.* They were concerned with all three of the dimensions of space.

In his memoir of 1784, HERSCHEL says:

"Hitherto the sidereal heavens have, not inadequately for the purpose designed, been represented by the concave surface of a sphere, in the centre of which the eye of an observer might be supposed to be placed.

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* The memoirs on the parallaxes of stars, written by various astronomers from 1750 to 1800, were mainly directed to the improvement of the methods, or to the discovery of the parallax of some particular star. For example, LACAILLE's observations of *Sirius*, at the Cape of Good Hope, had resulted in a parallax of 9″ for that star—a quantity over forty times too large.

"It is true the various magnitudes of the fixed stars even then plainly suggested to us, and would have better suited, the idea of an expanded firmament of three dimensions; but the observations upon which I am now going to enter still farther illustrate and enforce the necessity of considering the heavens in this point of view. In future, therefore, we shall look upon those regions into which we may now penetrate by means of such large telescopes, as a naturalist regards a rich extent of ground or chain of mountains containing strata variously inclined and directed, as well as consisting of very different materials. The surface of a globe or map, therefore, will but ill delineate the interior parts of the heavens."

HERSCHEL's method of study was founded on a mode of observation which he called *star-gauging*. It consisted in pointing a powerful telescope toward various parts of the heavens, and ascertaining by actual count how thick the stars were in each region. His twenty-foot reflector was provided with such an eye-piece that, in looking into it, he saw a portion of the heavens about 15′ in diameter. A circle of this size on the celestial sphere has about one quarter the apparent surface of the sun, or of the full moon. On pointing the telescope in any direction, a greater or less number of stars were visible. These were counted, and the direction in which the telescope pointed was noted. Gauges of this kind were made in all parts of the sky, and the results were tabulated in the order of right ascension.

The following is an extract from the gauges, and gives the average number of stars in each field at the points noted in right ascension and north polar distance :

R. A. H.	R. A. M.	N. P. D. 78° to 80°. No. of Stars.	R. A. H.	R. A. M.	N. P. D. 92° to 94°. No. of Stars.
11	6	3.1	15	10	9.4
12	31	3.4	15	22	10.6
12	44	4.6	15	47	10.6
12	49	3.9	16	8	12.1
13	5	3.8	16	25	13.6
14	30	3.6	16	37	18.6

In this small table, it is plain that a different law of clustering or of distribution obtains in the two regions. Such differences are still more marked, if we compare the extreme cases found by HERSCHEL, as R. A.

= $19^h 41^m$, N. P. D. = $74° 33'$, number of stars per field = 588; and R. A. = $16^h 10^m$, N. P. D. = $113° 4'$, number of stars = 1.1.

The number of stars in certain portions is very great. For example, in the Milky Way, near *Orion*, six fields of view promiscuously taken gave 110, 60, 70, 90, 70, and 74 stars each, or a mean of 79 stars per field. The most vacant space in this neighborhood gave 60 stars. So that as HERSCHEL'S sweeps were two degrees wide in declination, in one hour (15°) there would pass through the field of his telescope 40,000 or more stars. In some of the sweeps this number was as great as 116,000 stars in a quarter of an hour.

When HERSCHEL first applied his telescope to the Milky Way, he believed that it completely resolved the whole whitish appearance into small stars. This conclusion he subsequently modified. He says:

"It is very probable that the great stratum called the Milky Way is that in which the sun is placed, though perhaps not in the very centre of its thickness.

"We gather this from the appearance of the Galaxy, which seems to encompass the whole heavens, as it certainly must do if the sun is within it. For, suppose a number of stars arranged between two parallel planes, indefinitely extended every way, but at a given considerable distance from each other; and calling this a sidereal stratum, an eye placed somewhere within it will see all the stars in the direction of the planes of the stratum projected into a great circle, which will appear lucid on account of the accumulation of the stars, while the rest of the heavens, at the sides, will only seem to be scattered over with constellations, more or less crowded according to the distance of the planes, or number of stars contained in the thickness or sides of the stratum.

"If the eye were placed somewhere without the stratum, at no very great distance, the appearance of the stars within it would assume the form of one of the smaller circles of the sphere, which would be more or less contracted according to the distance of the eye; and, if this distance were exceedingly increased, the whole stratum might at last be drawn together into a lucid spot of any shape, according to the length, breadth, and height of the stratum.

"Suppose that a smaller stratum should branch out from the former in a certain direction, and that it also is contained between two parallel planes, so that the eye is contained within the great stratum somewhere before the separation, and not far from the place where the strata are still united. Then this second stratum will not be projected into a bright circle like the former, but it will be seen as a lucid branch proceeding from the first, and returning into it again at a distance less than a semicircle. If the bounding surfaces are not parallel planes, but irregularly curved surfaces, analogous appearances must result."

The Milky Way, as we see it, presents the aspect which has been just accounted for, in its general appearance of a girdle around the heavens and in its bifurcation at a certain point, and HERSCHEL's explanation of this appearance, as just given, has never been seriously questioned. One doubtful point remains: are the stars scattered all through space? or are they near its bounding planes, or clustered in any way within this space so as to produce the same result to the eye as if uniformly distributed?

HERSCHEL assumed that they were nearly equably arranged all through the space in question. He only examined one other arrangement, *viz.*, that of a ring of stars surrounding the sun, and he pronounced against such an arrangement, for the reason that there is absolutely nothing in the size or brilliancy of the sun to cause us to suppose it to be the centre of such a gigantic system. No reason, except its importance to us personally, can be alleged for such a supposition. Every star will have its own appearance of a Galaxy or Milky Way, which will vary according to the situation of the star.

Such an explanation will account for the general appearances of the Milky Way and of the rest of the sky, supposing the stars equally or nearly equally distributed in space. On this supposition, the system must be deeper where the stars appear most numerous.

HERSCHEL endeavored, in his early memoirs, to explain this inequality of distribution on the fundamental assumption that the stars were nearly equably distributed in space. If they were so distributed, then the number of stars visible in any gauge would show the thickness of the stellar system in the direction in which the telescope was pointed. At each pointing, the field of view of the instrument includes all the visible stars situated within a cone, having its vertex at the observer's eye, and its base at the very limits of the system, the angle of the cone (at the eye) being 15′. Then the cubes of the perpendiculars let fall from the eye, on the plane of the bases of the various visual cones, are proportional to the solid contents of the cones themselves, or, as the stars are supposed equally scattered within all the cones, the cube roots of the numbers of stars in each of the fields express the relative lengths of the perpendiculars. A *section* of the sidereal system along any great circle can be constructed from the data furnished by the gauges in the following way:

The solar system is within the mass of stars. From this point lines are drawn along the different directions in which the gauging telescope was pointed. On these lines are laid off lengths proportional to the cube roots of the number of stars in each gauge. The irregular line joining the terminal points will be approximately the bounding curve of the stellar system in the great circle chosen. Within this line the space is nearly uniformly filled with stars. Without it is empty space. A similar section can be constructed in any other great circle, and a combination of all such would give a representation of the shape of our stellar system. The more numerous and careful the observations, the more elaborate the representation, and the 863 gauges of HERSCHEL are sufficient to mark out with great precision the main features of the Milky Way, and even to indicate some of its chief irregularities.

On the fundamental assumption of HERSCHEL (equable distribution), no other conclusion can be drawn from his statistics but the one laid down by him.

This assumption he subsequently modified in some degree, and was led to regard his gauges as indicating not so much the *depth of the system* in any direction, as the *clustering power or tendency* of the stars in those special regions. It is clear that if in any given part of the sky, where, on the average, there are ten stars (say) to a field, we should find a certain small portion having 100 or more to a field, then, on HERSCHEL'S first hypothesis, rigorously interpreted, it would be necessary to suppose a spike-shaped protuberance directed from the earth, in order to explain the increased number of stars. If many such places could be found, then the probability is great that this explanation is wrong. We should more rationally suppose some real inequality of star distribution here. It is, in fact, in just such details that the method of HERSCHEL breaks down, and a careful examination of his system leads to the belief that it must be greatly modified to cover all the known facts, while it undoubtedly has, in the main, a strong basis.

The stars are certainly not uniformly distributed, and any general theory of the sidereal system must take into account the varied tendency to aggregation in various parts of the sky.

In 1817, HERSCHEL published an important memoir on the same subject, in which his first method was largely modified, though not abandoned. Its fundamental principle was stated by him as follows:

"It is evident that we cannot mean to affirm that the stars of the fifth, sixth, and seventh magnitudes are really smaller than those of the first, second, or third, and that we must ascribe the cause of the difference in the apparent magnitudes of the stars to a difference in their relative distances from us. On account of the great number of stars in each class, we must also allow that the stars of each succeeding magnitude, beginning with the first, are, one with another, further from us than those of the magnitude immediately preceding. The relative magnitudes give only relative distances, and can afford no information as to the real distances at which the stars are placed.

"A standard of reference for the arrangement of the stars may be had by comparing their distribution to a certain properly modified equality of scattering. The equality which I propose does not require that the stars should be at equal distances from each other, nor is it necessary that all those of the same nominal magnitude should be equally distant from us."

It consisted in allotting a certain equal portion of space to every star, so that, on the whole, each equal portion of space within the stellar system contains an equal number of stars. The space about each star can be considered spherical. Suppose such a sphere to surround our own sun. Its radius will not differ greatly from the distance of the nearest fixed star, and this is taken as the unit of distance.

Suppose a series of larger spheres, all drawn around our sun as a centre, and having the radii 3, 5, 7, 9, etc. The contents of the spheres being as the cubes of their diameters, the first sphere will have $3 \times 3 \times 3 = 27$ times the volume of the unit sphere, and will therefore be large enough to contain 27 stars; the second will have 125 times the volume, and will therefore contain 125 stars, and so on with the successive spheres. For instance, the sphere of radius 7 has room for 343 stars, but of this space 125 parts belong to the spheres inside of it; there is, therefore, room for 218 stars between the spheres of radii 5 and 7.

HERSCHEL designates the several distances of these layers of stars as orders; the stars between spheres 1 and 3 are of the first order of distance, those between 3 and 5 of the second order, and so on. Comparing the room for stars between the several spheres with the number of stars of the several magnitudes which actually exists in the sky, he found the result to be as follows:

Order of Distance.	Number of Stars there is Room for.	Magnitude.	Number of Stars of that Magnitude.
1........	26	1	17
2........	98	2	57
3........	218	3	206
4........	386	4	454
5........	602	5	1,161
6........	866	6	6,103
7........	1,178	7	6,146
8........	1,538		

The result of this comparison is, that if the order of magnitudes could indicate the distance of the stars, it would denote at first a gradual and afterward a very abrupt condensation of them, at and beyond the region of the sixth-magnitude stars.

If we assume the brightness of any star to be inversely proportional to the square of its distance, it leads to a scale of distance different from that adopted by HERSCHEL, so that a sixth-magnitude star on the common scale would be about of the eighth order of distance according to this scheme—that is, we must remove a star of the first magnitude to eight times its actual distance to make it shine like a star of the sixth magnitude.

On the scheme here laid down, HERSCHEL subsequently assigned the *order* of distance of various objects, mostly star-clusters, and his estimates of these distances are still quoted. They rest on the fundamental hypothesis which has been explained, and the error in the assumption of equal intrinsic brilliancy for all stars affects these estimates. It is perhaps probable that the hypothesis of equal brilliancy for all stars is still more erroneous than the hypothesis of equal distribution, and it may well be that there is a very large range indeed in the actual dimensions and in the intrinsic brilliancy of stars at the same order of distance from us, so that the tenth-magnitude stars, for example, may be scattered throughout the spheres which HERSCHEL would assign to the seventh, eighth, ninth, tenth, eleventh, twelfth, and thirteenth magnitudes. However this may be, the fact remains that it is from HERSCHEL'S groundwork that future investigators must build. He found the whole subject in utter confusion. By his observations, data for the solution of some of the most general questions were accumulated, and in his memoirs, which STRUVE well calls "immortal," he brought the scattered facts into order and gave the first bold outlines of a reasonable theory. He is the founder of a new branch of astronomy.

Researches for a Scale of Celestial Measures. Distances of the Stars.

If the stars are *supposed* all of the same absolute brightness, their brightness to the eye will depend only upon their distance from us. If we call the brightness of one of the fixed stars at the distance of *Sirius*, which may be used as the unity of distance, 1, then if it is moved to the distance 2, its apparent brightness will be one-fourth; if to the distance 3, one-ninth; if to the distance 4, one-sixteenth, and so on, the apparent brightness diminishing as the square of the distance increases. The distance may be taken as an order of magnitude. Stars at the *distances* two, three, four, etc., HERSCHEL called of the second, third, and fourth magnitudes.

By a series of experiments, the details of which cannot be given here, HERSCHEL determined the space-penetrating power of each of his telescopes. The twenty-foot would penetrate into space seventy-five times farther than the naked eye; the twenty-five foot, ninety-six times; and the forty-foot, one hundred and ninety-two times. If the seventh-magnitude stars are those just visible to the naked eye, and if we still suppose all stars to be of equal intrinsic brightness, such seventh-magnitude stars would remain visible in the forty-foot, even if removed to 1,344 times the distance of *Sirius* ($1,344 = 7 \times 192$). If, further, we suppose that the visibility of a star is strictly proportional to the total intensity of the light from it which strikes the eye, then a condensed cluster of 25,000 stars of the 1,344th magnitude could still be seen in the forty-foot at a distance where each star would have become 25,000 times fainter, that is, at about 158 times the distance of *Sirius*

(158 × 158 = 24,964). The light from the nearest star requires some three years to reach the earth. From a star 1,344 times farther it would require about 4,000 years, and for such a cluster as we have imagined no less than 600,000 years are needed. That is, the light by which we see such a group has not just now left it. On the contrary, it has been travelling through space for centuries and centuries since it first darted forth. It is the ancient history of such groups that we are studying now, and it was thus that HERSCHEL declared that telescopes penetrated into time as well as into space.

Other more exact researches on the relative light of stars were made by HERSCHEL. These were only one more attempt to obtain a scale of celestial distances, according to which some notion of the limits and of the interior dimensions of the universe could be gained. Two telescopes, *exactly equal* in every respect, were chosen and placed side by side. Pairs of stars which were *exactly equal*, were selected by means of them. By diminishing the aperture of one telescope directed to a bright star, and keeping the other telescope unchanged and directed to a fainter star, the two stars could be equalized in light, and, from the relative size of the apertures, the relative light of this pair of stars could be accurately computed, and so on for other pairs. This was the first use of the method of *limiting apertures.* His general results were that the stars of the first magnitude would still remain visible to the naked eye, even if they were at a distance from us *twelve* times their actual distance.

This method received a still further development at his hands. He did not leave it until he had gained all the information it was capable of giving. He prepared a set of telescopes collecting 4, 9, 16, etc. (2 × 2, 3 × 3, 4 × 4, etc.), times as much light as the naked eye. These were to extend the determinations of distance to the telescopic stars. For example, a certain portion of the heavens which he examined contained no star visible to the naked eye, but many telescopic stars. We cannot say that no one of these is as bright in itself as some of our first-magnitude stars. The smallest telescope of the set showed a large number of stars; these must, then, be *twice* as far from us, on the average, as the stars just visible to the naked eye. But first-magnitude stars, like *Sirius*, *Procyon*, *Arcturus*, etc., become just visible to the eye if removed to twelve times their present distance. Hence the stars seen in this first telescope of the set were between twelve and twenty-four times as far from us as *Arcturus*, for example.

"At least," as HERSCHEL says, "we are certain that if stars of the size and lustre of *Sirius*, *Arcturus*, etc., were removed into the profundity of space I have mentioned, they would then appear like the stars which I saw." With the next telescope, which collected nine times more light than the eye, and brought into view objects three times more distant, other and new stars appeared, which were then (3 × 12) thirty-six times farther from us than *Arcturus*. In the same way, the seven-foot reflector showed stars 204 times, the ten-foot 344 times, the twenty-foot 900 times farther from us than the average first-magnitude star. As the light from such a star requires three years to reach us, the light from the faintest stars seen by the twenty-foot would require 2,700 years (3 × 900).

But HERSCHEL was now (1817) convinced that the twenty-foot telescope could not penetrate to the boundaries of the Milky Way; the faintest stars of the Galaxy must then be farther from us even than nine hundred times the distance of *Arcturus*, and their light must be at least 3,000 years old when it reaches us.

There is no escaping a certain part of the consequences established by HERSCHEL. It is indeed true that unless a particular star is of the same intrinsic brightness as our largest stars, this reasoning does not apply to it; in just so far as the average star is less bright than the average brightness of our largest stars, will the numbers which HERSCHEL obtained be diminished. But for every star of which his hypothesis is true, we may assert that his conclusions are true, and no one can deny, with any show of reason, that, on the whole, his suppositions must be valid. On the whole, the stars which we call faint are farther from us than the brighter ones; and, on the whole, the brilliancy of our brightest and nearest stars is not very far from the brilliancy of the average star in space. We cannot yet define the word *very* by a numerical ratio.

The *method* struck out by HERSCHEL was correct; it is for his successors to look for the special cases and limitations, to answer the question, At a certain distance from us, what are the variations which actually take place in the brilliancy and the sizes of stars? The answer to this question is to be found in the study of the clusters of regular forms, where we *know* the stars to be all at the same distance from us.

Researches on Light and Heat, Etc.

Frequently in the course of his astronomical work, HERSCHEL found himself confronted by questions of physics which could not be immediately answered in the state of the science at that time. In his efforts to find a method for determining the dimensions of the stellar universe, he was finally led, as has been shown, to regard the brightness of a star as, in general, the best attainable measure of its distance from us. His work, however, was done with telescopes of various dimensions and powers, and it was therefore necessary to find some law for comparing the different results among themselves as well as with those given by observations with an unassisted eye. This necessity prompted an investigation, published in 1800, in which, after drawing the distinction between absolute and intrinsic brightness, HERSCHEL gave an expression for the *space-penetrating power* of a telescope. The reasoning at the base of this conception was as follows.

The ratio of the light entering the eye when directed toward a star, to the whole light given out by the star, would be as the area of the pupil of the eye to the area of the whole sphere having the star as a centre and our distance from the star as a radius.

If the eye is assisted by a telescope, the ratio is quite different. In that case the ratio of the light which enters the eye to the whole light, would be as the area of the mirror or object-glass to the area of the whole sphere having the star as a centre and its distance as a radius. Thus the light received by the *eye* in the two cases would be as the area of the pupil is to the area of the object-glass. For instance, if the pupil has a diameter of two-fifths of an inch, and the mirror a diameter of four inches, then a hundred times as much light would enter the eye when assisted by the telescope as when unarmed, since the *area* of the pupil is one-hundredth the *area* of the objective.

If a particular star is just visible to the naked eye, it will be quite bright if viewed with this special telescope, which makes it one hundred times more brilliant in appearance. If we could move the star bodily away from us to a distance ten times its present distance, we could thus reduce its brightness, as seen with the telescope, to what it was at first, as seen with the eye alone, *i. e.*, to bare visibility. Moving the star to ten times its present distance would increase the surface of the sphere which it illuminates a hundred-fold. We cannot move any special star, but we can examine stars of all brightnesses, and thus (presumably) of all distances.

HERSCHEL's argument was, then, as follows: Since with such a telescope one can see a star ten times as far off as is possible to the naked eye, this telescope has the power of penetrating into space ten times farther than the eye alone. But this number ten, also, expresses the ratio of the diameter of the objective to that of the pupil of the eye, consequently the general law is that the *space-penetrating power* of a telescope is found by dividing the diameter of the mirror in inches by two-fifths. The diameter of the pupil of the eye (two-fifths of an inch) HERSCHEL determined by many measures.

This simple ratio would only hold good, however, provided no more light were lost by the repeated reflections and refractions in the telescope than in the eye. That light must be so lost was evident, but no data existed for determining the loss. HERSCHEL was thus led to a long series of photometric experiments on the reflecting powers of the metals used in his mirrors, and on the amount of light transmitted by lenses. Applying the corrections thus deduced experimentally, he found that the space-penetrating power of his twenty-foot telescope, with which he made his star-gauges, was sixty-one times that of the unassisted eye, while the space-penetrating power of his great forty-foot telescope was one hundred and ninety-two times that of the eye. In support of his important conclusions HERSCHEL had an almost unlimited amount of experimental data in the records of his observations, of which he made effective use.

By far the most important of HERSCHEL'S work in the domain of pure physics was published in the same year (1800), and related to radiant heat. The investigation of the space-penetrating powers of telescopes was undertaken for the sole purpose of aiding him in measuring the dimensions of the stellar universe, and there was no temptation for him to pursue it beyond the limits of its immediate usefulness. But here, though the first hint leading to remarkable discoveries was a direct consequence of his astronomical work, the novelty and interest of the phenomena observed induced him to follow the investigation very far beyond the mere solution of the practical question in which it originated.

Having tried many varieties of shade-glasses between the eye-piece of his telescope and the eye, in order to reduce the inordinate degree of heat and light transmitted by the instrument when directed towards the sun, he observed that certain combinations of colored glasses permitted very little light to pass, but transmitted so much heat that they could not be used; while, on the other hand, different combinations and differently colored glasses would stop nearly all the heat, but allow an inconveniently great amount of light to pass. At the same time he noticed, in the various experiments, that the images of the sun were of different colors. This suggested the question as to whether there was not a different heating power proper to each color of the spectrum. On comparing the readings of sensitive thermometers exposed in different portions of an intense solar spectrum, he found that, beginning with the violet end, he came to the maximum of light long before that of heat, which lay at the other extremity, that is, near the red. By several experiments it appeared that the maximum of illumination, *i. e.*, the yellow, had little more than half the heat of the full red rays; and from other experiments he concluded that even the full red fell short of the maximum of heat, which, perhaps, lay even a little beyond the limits of the visible spectrum.

"In this case," he says, "radiant heat will at least partly, if not chiefly, consist, if I may be permitted the expression, of invisible light; that is to say, of rays coming from the sun, that have such a momentum * as to be unfit for vision. And admitting, as is highly probable, that the organs of sight are only adapted to receive impressions from particles of a certain momentum, it

* HERSCHEL accepted, as did all his cotemporaries, the Newtonian or corpuscular theory of light.

explains why the maximum of illumination should be in the middle of the refrangible rays; as those which have greater or less momenta are likely to become equally unfit for the impression of sight."

In his second paper on this subject, published in the same year, HERSCHEL describes the experiments which led to the conclusion given above. This paper contains a remarkably interesting passage which admirably illustrates HERSCHEL's philosophic method.

"To conclude, if we call light, those rays which illuminate objects, and radiant heat, those which heat bodies, it may be inquired whether light be essentially different from radiant heat? In answer to which I would suggest that we are not allowed, by the rules of philosophizing, to admit two different causes to explain certain effects, if they may be accounted for by one. . . . If this be a true account of the solar heat, for the support of which I appeal to my experiments, it remains only for us to admit that such of the rays of the sun as have the refrangibility of those which are contained in the prismatic spectrum, by the construction of the organs of sight, are admitted under the appearance of light and colors, and that the rest, being stopped in the coats and humors of the eye, act on them, as they are known to do on all the other parts of our body, by occasioning a sensation of heat."

We now know that the reasoning and conclusion here given are entirely correct, but they have for their basis only a philosophical conception, and not a series of experiments designed especially to test their correctness. Such an experimental test of this important question was the motive for a third and last paper in this department of physics. This paper was published in volume ninety of the *Philosophical Transactions*, and gave the results of two hundred and nineteen quantitative experiments.

Here we are at a loss to know which to admire most—the marvellous skill evinced in acquiring such accurate data with such inadequate means, and in varying and testing such a number of questions as were suggested in the course of the investigation—or the intellectual power shown in marshalling and reducing to a system such intricate and apparently self-contradictory phenomena. It is true that this discussion led him to a different conclusion from that announced in the previous paper, and, consequently, to a false conclusion; but almost the only escape from his course of reasoning lay in a principle which belongs to a later period of intellectual development than that of HERSCHEL'S own time.

HERSCHEL made a careful determination of the quantitative distribution of light and of heat in the prismatic spectrum, and discovered the surprising fact that not only where the light was at a maximum the heat was very inconsiderable, but that where there was a maximum exhibition of heat, there was not a trace of light.

"This consideration," he writes, "must alter the form of our proposed inquiry; for the question being thus at least partly decided, since it is ascertained that we have rays of heat which give no light, it can only become a subject of inquiry whether some of these heat-making rays may not have a power of rendering objects visible, superadded to their now already established power of heating bodies. This being the case, it is evident that the *onus probandi* ought to lie with those who are willing to establish such an hypothesis, for it does not appear that Nature is in the habit of using one and the same mechanism with any two of our senses. Witness the vibration of air that makes sound, the effluvia that occasion smells, the particles that produce taste, the resistance or repulsive powers that affect the touch—all these are evidently suited to their respective organs of sense."

It is difficult to see how the fallacy of this argument could have been detected by any one not familiar with the fundamental physiological law that the nature of a sensation is in no wise determined by the character of the agent producing it, but only by the character of the nerves acted upon ; but, as already intimated, this law belongs to a later epoch than the one we are considering. HERSCHEL thus finally concluded that light and radiant heat were of essentially different natures, and upon this supposition he explained all of the phenomena which his numerous experiments had shown him. So complete and satisfactory did this work appear to the scientific world, that for a long time the question was looked upon as closed, and not until thirty-five years later was there any dissent. Then the Italian physicist, MELLONI, with instrumental means a thousand times more delicate than that of HERSCHEL, and with a far larger store of cognate phenomena, collected during the generation which had elapsed, to serve as a guide, discovered the true law. This, as we have seen, was at first adopted by HERSCHEL on philosophical grounds, and then rejected, since he did not at that time possess the key which alone could have enabled him to properly interpret his experiments.

It is well to summarize the capital discoveries in this field made by HERSCHEL, more particularly because his claims as a discoverer seem to have been strangely overlooked by historians of the development of physical science. He, before any other investigator, showed that radiant heat is refracted according to the laws governing the refraction of light by transparent media; that a portion of the radiation from the sun is incapable of exciting the sensation of vision, and that this portion is the less refrangible; that the different colors of the spectrum possess very unequal heating powers, which are not proportional to their luminosity; that substances differ very greatly in their power of transmitting radiant heat, and that this power does not depend solely upon their color; and that the property of diffusing heat is possessed to a varying degree by different bodies, independently of their color. Nor should we neglect to emphasize, in this connection, the importance of his measurements of the intensity of the heat and light in the different portions of the solar spectrum. It is the more necessary to state HERSCHEL's claims clearly, as his work has been neglected by those who should first have done him justice. In his "History of Physics," POGGENDORFF has no reference to HERSCHEL. In the collected works of VERDET, long bibliographical notes are appended to each chapter, with the intention of exhibiting the progress and order of discovery. But all of HERSCHEL's work is overlooked, or indexed under the name of his son. One little reference in the text alone shows that his very name was not unknown. Even in the great work of HELMHOLTZ on physiological optics, HERSCHEL's labors are not taken account of.

It is easy to account for this seemingly strange neglect. HERSCHEL is known to this generation only as an astronomer. A study of his memoirs will show that his physical work alone should give him a very high rank indeed, and I trust that the brief summaries, which alone can be given here, will have made this plain.

We may conclude from the time expended, the elaborate nature of the experiments involved, and the character of the papers devoted to their consideration, that the portion of HERSCHEL'S researches in physics which interested him to the greatest degree, was the investigation of the optical phenomena known as NEWTON'S rings. In 1792 he obtained the two object-glasses of HUYGHENS, which were in the possession of the Royal Society, for the purpose of repeating NEWTON'S experiments, and in 1810 he read the last of his three papers on the subject.

Sir ISAAC NEWTON had given some of his most vigorous efforts to the study of the phenomena of interference of light, which are exemplified in the colors of thin and of thick plates. The colors of thin plates are most conveniently studied in the regular form which they present when produced by a thin plate of air, limited on one side by a plane polished surface, and on the other by a spherical surface of long radius, such as the exterior surface of a convex lens, for example. The colors are then arranged in concentric circles, and, though others had so produced them before NEWTON, these rings have, ever since the publication of his remarkable work, been known by his name.

To explain the phenomena, NEWTON was obliged to supplement his theory of the corpuscular nature of light, by supposing that the inconceivably minute particles constituting light are not always equally susceptible of reflection, but that they have periodically recurring "fits of easy reflection" and of "easy transmission." This conception, though by no means unphilosophical, seemed to HERSCHEL too artificial and improbable for ready acceptance, and his effort was to supply a more probable explanation.

The developments of optical science have justified HERSCHEL in his objections, but we cannot accord to him any considerable part in making clear the true nature of the phenomenon. Indeed, it must be recognized that his position was distinctly less advanced than that of NEWTON. That great philosopher announced the true law governing the relation between the color and the thickness of the film. HERSCHEL did not recognize such a relation. NEWTON showed exactly how the phenomenon depended upon the obliquity at which it was viewed. HERSCHEL found no place in his theory for this evident variation.

In the series of experiments described in the first paper on this subject, HERSCHEL mistook the locus of a certain set of rings which he was observing. This mistake, though so slight as hardly to be detected without the guidance of the definite knowledge acquired in later times, not only vitiated the conclusion from the experiments, but gave an erroneous direction to the whole investigation. To him these experiments proved that NEWTON's conception of a periodic phenomenon was untenable. Thus cut loose from all hypothesis, his fertility in ideas and ingenuity in experimentation are as striking as ever. He tried the effect of having a polished metal as one of the surfaces limiting the thin plate of air. Observing the so-called "blue bow" of NEWTON at the limit of total reflection in a prism, he was led to the discovery of its complement, the "red bow" by refraction. Here he thought he had found the solution of his problem, and attributed the rings to the reflection of the light which passed through in the red bow. Though mistaken, he had presented to the world of science two experiments which have since played very prominent parts in the undulatory theory of light, namely, the rings formed upon polished metal, and the bands produced by a thin plate near the critical angle.

As in his later researches upon the nature of radiant heat, he was wrong in his conclusions, and perhaps with less excuse. His experiments were skilfully devised and most ingenious. His philosophizing was distinctly faulty. We can see not only that he was wrong, but exactly where he began to go wrong. Yet these papers are full of interest to the physicist, and by no means deserve the neglect into which they have fallen.

Researches on the Dimensions of the Stars.

HERSCHEL examined a number of bright stars, using extremely high magnifying powers, in order to determine whether the stars have sensible dimensions. In a good telescope stars present round and pretty uniformly illuminated disks. If these disks really represent the angular diameter of the stars, they should admit of magnifying, like other objects; but, instead of this, HERSCHEL found that they appeared smaller as the telescopic power was increased. He accordingly called the disk of light seen in the telescope a spurious disk. This singular phenomenon gave its discoverer a ready criterion for determining whether a small bright body has an appreciable size, or only impresses the sense of sight by virtue of its intrinsic brightness. If the first were the case, the apparent size would increase with increased magnifying power, while, if the angular dimensions were inappreciable, the apparent size would, on the contrary, diminish with additional magnifying. An occasion for using this criterion came in the first years of this century, with the discovery of three small planets having orbits lying between those of *Mars* and *Jupiter*. HERSCHEL gave the name *Asteroids* to these bodies. As the appropriateness of this term had been violently assailed, the discovery of *Juno*, in 1804, the third one of the group, led to a careful experimental study of the defining power of the telescope used, and of the laws governing the phenomena of spurious disks.

With a telescope of about nine inches in aperture, HERSCHEL found that if *Juno* subtended an angle greater than a quarter of a second of arc, a certain indication of the fact would have shown itself in the course of the experiments. This conclusion was a justification of the name Asteroid, since the appearance of the new planet was strictly stellar. On other grounds, a better name might have been selected.

In the paper giving the results of the experiments, the phenomena of the spurious disks are very completely described; but they did not attract the attention which they deserved, and they only became an object of especial interest to students of physics when they were again studied by the famous German optician FRAUNHOFER, a generation later.

Incidentally the experiments are of interest, as yielding us a measure of the excellence of HERSCHEL'S telescopes, and a measure which is quite independent of the keenness of his vision. From them we may be sure that the efficiency of the nine-inch mirror used was not sensibly less than that of the highest theoretically attainable excellence. In this connection, too, we may refer to the *Philosophical Transactions* for 1790, pp. 468 and 475, where HERSCHEL gives observations of both *Enceladus* and *Mimas* seen in contact with the ball of *Saturn*. I have never seen so good definition, telescopic and atmospheric, as he must have had on these occasions.

Researches on the Spectra of the Fixed Stars.

The spectroscope was applied by SECCHI to the study of the spectra of the fixed stars visible to the naked eye in the years 1863 to 1866. He examined the nature of the spectrum of each of the larger stars, and found that these stars could be arranged in three general classes or *types*. His results have been verified and extended by other astronomers, and his classification has been generally accepted. According to SECCHI, the lucid stars may be separated into three groups, distinguished by marked differences in their spectra. SECCHI's Type I. contains stars whose spectra are like those of *Sirius*, *Procyon*, and *α Lyræ;* his Type II. stars like *Arcturus* and *Aldebaran;* his Type III. stars like *α Orionis*.

HERSCHEL also made some trials in this direction. In the *Philosophical Transactions* for 1814 (p. 264), he says:

"By some experiments on the light of a few of the stars of the first magnitude, made in 1798, by a prism applied to the eye-glasses of my reflectors, adjustable to any angle and to any direction, I had the following analyses:

"The light of *Sirius* consists of red, orange, yellow, green, blue, purple, and violet. *α Orionis* contains the same colors, but the red is more intense, and the orange and yellow are less copious in proportion than they are in *Sirius*. *Procyon* contains all the colors, but proportionately more blue and purple than *Sirius*. *Arcturus* contains more red and orange, and less yellow in proportion than *Sirius*. *Aldebaran* contains much orange and very little yellow. *α Lyræ* contains much yellow, green, blue, and purple."

Here the essential peculiarities of the spectrum of each of the stars investigated by HERSCHEL is pointed out, and if we were to use his observations alone to classify these stars into types, we should put *Sirius* and *Procyon* into one type of stars which have "all the colors" in their spectra; *Arcturus* and *Aldebaran* would represent another group of stars, with a deficiency of yellow and an excess of orange and red in the spectrum; and *α Orionis* would stand as a type of those stars with an excess of red and a deficiency of orange. *α Lyræ* would represent a sub-group of the first class.

HERSCHEL'S immediate object was not classification, and his observations are only recorded in a passing way. But the fact remains that he clearly distinguished the essential differences of the spectra of these stars, and that he made these observations in support of his statement that the fixed stars, "like the planets, also shine with differently colored light. That of *Arcturus* and *Aldebaran*, for instance, is as different from the light of *Sirius* and *Capella* as that of *Mars* and *Saturn* is from the light of *Venus* and *Jupiter*."

Of course, no special discovery can be claimed for him on these few instances. We can see, however, a good example of the manner in which he examined a subject from every side, and used the most remote evidence exactly in its proper place and time.

Researches on the Variable Emission of Light and Heat from the Sun.

It is certainly a remarkable fact that HERSCHEL was the first observer to recognize the real importance of the aperture or diameter of a telescope. Before his time it was generally assumed that this element only conditioned the amount of light transmitted to the eye, or, in other words, merely determined the brightness of the image. Hence the conclusion that if an object is sufficiently bright, the telescope may be made as small as desired without loss of power. Thus, in observing the sun, astronomers before HERSCHEL had been accustomed to reduce the aperture of their telescopes, in order to moderate the heat and light transmitted. SCHEINER, it is true, nearly two centuries before the time we are considering, had invented a method for observing the sun without danger, still employing the full aperture. This was by projecting the image of the sun on a white screen beyond the eye-piece, the telescope being slightly lengthened. For special purposes this ingenious method has even been found useful in modern times, though for sharpness of definition it bears much the same relation to the more usual manner of observing, that a photographic picture does to direct vision.

Although HERSCHEL saw the advantages of using the whole aperture of a telescope in such observations, the practical difficulties in the way were very great. We have noted his attempts to find screens which would effectively cut off a large portion of the heat and light without impairing vision, and have considered, somewhat in detail, the remarkable discoveries in radiant heat to which these attempts led him. His efforts were not unsuccessful. A green glass smoked, and a glass cell containing a solution of black writing ink in water—were found to work admirably.

Thus provided with more powerful instrumental means than had ever been applied to the purpose, HERSCHEL turned his attention to the sun. In a very short time he exhausted nearly all there was to be discovered, so that since the publication of his last paper on this subject, in 1801, until the present time, there has been but a single telescopic phenomenon, connected with the physical appearance of the sun, which was unknown to HERSCHEL. That phenomenon is the frequent occurrence of a darker central shade or kernel in large spots, discovered by DAWES about 1858.

HERSCHEL, though observing a hundred and ninety years after the earliest discovery of sun spots, seems to have been the first to suspect their periodic character. To establish this as a fact, and to measure the period, was left for our own times and for the indefatigable observer SCHWABE. The probable importance of such a period in its relation to terrestrial meteorology was not only clearly pointed out by HERSCHEL, but he even attempted to demonstrate, from such data as were obtainable, the character of this influence.

Perhaps no one thing which this great philosopher has done better exhibits the catholic character of his mind than this research. When the possible connection of solar and terrestrial phenomena occurred to him as a question to be tested, there were no available meteorological records, and he could find but four or five short series of observations, widely separated in time. To an ordinary thinker the task would have seemed hopeless until more data had been collected. But HERSCHEL'S fertile mind, though it could not recall lost opportunities for solar observations, did find a substitute for meteorological records in the statistics of the prices of grain during the various epochs. It is clear that the price of wheat must have depended upon the supply, and the supply, in turn, largely upon the character of the season. The method, as ingenious as it is, failed in HERSCHEL'S hands on account of the paucity of solar statistics; but it has since proved of value, and has taken its place as a recognized method of research.

Researches on Nebulæ and Clusters.

When HERSCHEL first began to observe the nebulæ in 1774, there were very few of these objects known. The nebulæ of *Orion* and *Andromeda* had been known in Europe only a little over a hundred years.

In 1784 MESSIER published a list of sixty-eight such objects which he had found in his searches for comets, and twenty-eight nebulæ had been found by LACAILLE in his observations at the Cape of Good Hope. In the mere discovery of these objects HERSCHEL quickly surpassed all others. In 1786 he published a catalogue of one thousand new nebulæ, in 1789 a catalogue of a second thousand, and in 1802 one of five hundred. In all he discovered and described two thousand five hundred and eight new nebulæ and clusters. This branch of astronomy may almost be said to be proper to the HERSCHELS, father and son. Sir JOHN HERSCHEL re-observed all his father's nebulæ in the northern hemisphere, and added many new ones, and in his astronomical expedition to the Cape of Good Hope he recorded almost an equal number in the southern sky.

Of the six thousand two hundred nebulæ now known the HERSCHELS discovered at least eight-tenths. The mere discovery of twenty-five hundred nebulæ would have been a brilliant addition to our knowledge of celestial statistics.

HERSCHEL did more than merely point out the existence and position of these new bodies. Each observation was accompanied by a careful and minute description of the object viewed, and with sketches and diagrams which gave the position of the small stars in it and near it.*

As the nebulæ and clusters were discovered they were placed in classes, each class covering those nebulæ which resembled each other in their general features. Even at the telescope HERSCHEL's object was not discovery merely, but to know the inner constitu-

* Thus the position of small stars critically situated in the centre, or on the edges of the nebulæ was always noted. Many of the descriptions are given in the published papers, but the publication of the diagrams would be an immense help to this branch of astronomy. D'ARREST in his reduction of HERSCHEL's nebula observations (1856) writes: "Gewiss wäre es vom höchsten Interesse für die Entwickelung, welche hoffentlich auch dieser Zweig der beobachtenden Astronomie zukünftig erhalten wird, wenn die HERSCHEL'schen Beobachtungen in der Ausführlichkeit in welcher sie, verschiedenen Andeutungen zufolge, *handschriftlich* vorhanden sind, veröffentlicht würden. Es schliesst sich dieser Wunsch in Betreff der Nebelflecken lebhaft an den an, welcher, schon vor einem Jahrzehnt nach Veröffentlichung der 400 noch unedirten *star-gauges* von gewichtigerer Seite her geäussert wurde." In this all must agree who have a knowledge of the direction in which we must look for advances in the difficult and important questions of the distance, the motions, and the changes of the nebulæ. Almost the only aid to be looked for from the older observations must come from such diagrams, and we may safely say that the publication of this priceless material, just as it stands, would carry our exact data back from 1833 to 1786, or no less than forty-seven years.

tion of the heavens. His classes were arranged with this end, and they are to-day adopted. They were:

CLASS I. "Bright nebulæ (288 in all).
II. "Faint nebulæ (909 in all).
III. "Very faint nebulæ (984 in all).
IV. "Planetary nebulæ, stars with burs, with milky chevelure, with short rays, remarkable shapes, etc. (79 in all).
V. "Very large nebulæ (52 in all).
VI. "Very compressed and rich clusters of stars (42 in all).
VII. "Pretty much compressed clusters (67 in all).
VIII. "Coarsely scattered clusters of stars" (88 in all).

The lists of these classes were the storehouses of rich material from which HERSCHEL drew the examples by which his later opinions on the physical conditions of nebulous matter were enforced.

As the nebulæ were discovered and classified they were placed upon a star-map in their proper positions (1786), and, as the discoveries went on, the real laws of the distribution of the nebulæ and of the clusters over the surface of the sky showed themselves more and more plainly. It was by this means that HERSCHEL was led to the announcement of the law that the spaces richest in nebulæ are distant from the Milky Way, etc. By no other means could he have detected this, and I believe this to have been the first example of the use of the graphical method, now become common in treating large masses of statistics.

It is still in his capacity of an observer—an acute and wise one—that HERSCHEL is considered. But this was the least of his gifts. This vast mass of material was not left in this state: it served him for a stepping-stone to larger views of the nature and extent of the nebulous matter itself.

His views on the nature of nebulæ underwent successive changes. At first he supposed all nebulæ to be but aggregations of stars. The logic was simple. To the naked eye there are many groups of stars which appear nebulous. *Praesepe* is, perhaps, the best example. The slightest telescopic power applied to such groups alters the nebulous appearance, and shows that it comes from the combined and confused light of discrete stars. Other groups which remain nebulous in a seven-foot telescope, become stellar in a ten-foot. The nebulosity of the ten-foot can be resolved into stars by the twenty-foot, and so on. The nebulæ which remained still unresolved, it was reasonable to conclude, would yield to higher power, and generally a nebula was but a group of stars removed to a great distance. An increase of telescopic power was alone necessary to demonstrate this.*

"Nebulæ can be selected so that an insensible gradation shall take place from a coarse cluster like the *Pleiades* down to a milky nebulosity like that in *Orion*, every intermediate step being represented. This tends to confirm the hypothesis that all are composed of stars more or less remote."

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* Long after HERSCHEL had abandoned this idea, it continued current among astronomers. The successes of Lord ROSSE's telescope perpetuated to the middle of the nineteenth century an erroneous view which HERSCHEL had given up in 1791.

So, at first, HERSCHEL believed that his twenty-foot telescope was of power sufficient to fathom the Milky Way, that is, to see through it and beyond it, and to reduce all its nebulosities to true groups of stars.

In 1791 he published a memoir on *Nebulous Stars*, in which his views were completely changed. He had found a nebulous star, the sixty-ninth of his Class IV., to which his reasons would not apply. In the centre of it was a bright star; around the star was a halo gradually diminishing in brightness from the star outward, and perfectly circular. It was clear the two parts, star and nebula, were connected, and thus at the same distance from us.

There were two possible solutions only. Either the whole mass was, *first*, composed of stars, in which case the nucleus would be enormously larger than the other stars of its stellar magnitude elsewhere in the sky, or the stars which made up the halo indefinitely small; or, *second*, the central nucleus was indeed a star, but a star surrounded with "a shining fluid, of a nature totally unknown to us."

The long strata of nebulæ, which he had before described under the name of "telescopic Milky Ways," might well be accounted for by masses of this fluid lying beyond the regions of the seventh-magnitude stars. This fluid might exist independently of stars. If it is self-luminous, it seems more fit to produce a star by its condensation, than to depend upon the star for its own existence. Such were a few of the theorems to which his discovery of this nebula led him. The hypothesis of an elastic *shining fluid* existing in space, sometimes in connection with stars, sometimes distinct from them, was adopted and never abandoned. How well the spectroscope has confirmed this idea it is not necessary to say. We know the shining fluid does exist, and in late years we have seen the reverse of the process imagined by HERSCHEL. A star has actually, under our eyes, become a planetary nebula, and the cycle of which he gave the first terms is complete.

In five separate memoirs (1802, 1811, 1814, 1817, and 1818) HERSCHEL elaborated his views of the sidereal system. The whole extent of his views must be gained from the extended memoirs themselves. Here only the merest outline can be given.

In 1802 there is a marshaling of the various objects beyond our solar system. The stars themselves may be *insulated*, or may belong to *binary* or *multiple* systems, to *clusters* and groups, or to grand groups like the Milky Way. Nebulæ may have any of the forms which have been described; and, in 1811, he gives examples of immense spaces in the sky covered with diffused and very faint nebulosity. "Its abundance exceeds all imagination." * These masses of nebular matter are the seats of attracting forces, and these forces must produce condensation. When a nebula has more than one preponderating seat of attracting matter, it may in time be divided, and the double nebulæ have

* These have never been re-observed. They should be sought for with a powerful refractor, taking special precautions against the illumination of the field of view from neighboring bright stars. HERSCHEL'S reflectors were specially open to illusions produced in this way. His observations probably will remain untested until some large telescope is used in the way he adopted, *i. e.*, in sweeping.

had such an origin. When nebulæ appear to us as round masses, they are in reality globular in form, and this form is at once the effect and the proof of a gravitating cause.

The central brightness of nebulæ points out the seat of the attraction; and the completeness of the approximation to a spherical form points out the length of time that the gravitating forces have been at work. Those nebulæ (and clusters) which are most perfect in the globular form, have been longest exposed to central forces. The planetary nebulæ are the oldest in our system. They must have a rotatory motion on their axes.

By progressive condensation planetary nebulæ may be successively converted into bright stellar nebulæ, or into nebulous stars, and these again, by the effects of the same cause, into insulated or double stars. This chain of theorems, laid down in the memoir of 1811, is enforced in 1814 with examples which show how the nebulous appearance may grow into the sidereal. HERSCHEL selects from the hundreds of instances in his note-books, nebulæ in every stage of progress, and traces the effect of condensation and of clustering power through all its course, even to the final breaking up of the Milky Way itself.

The memoirs of 1817 and 1818 add little to the general view of the physical constitution of the heavens. They are attempts to gain a scale of celestial measures by which we may judge of the distances of the stars and clusters in which these changes are going on.

There is little to change in HERSCHEL'S statement of the general construction of the heavens. It is the groundwork upon which we have still to build. Every astronomical discovery and every physical fact well observed is material for the elaboration of its details or for the correction of some of its minor points. As a scientific conception it is perhaps the grandest that has ever entered into the human mind. As a study of the height to which the efforts of one man may go, it is almost without a parallel. The philosopher who will add to it to-day, will have his facts and his methods ready to his hands. HERSCHEL presents the almost unique example of an eager observer marshaling the multitude of single instances, which he himself has laboriously gathered, into a compact and philosophic whole. In spite of minor errors and defects, his ideas of the nature of the sidereal universe have prevailed, and are to-day the unacknowledged basis of our every thought upon it. Some of its most secret processes have been worked out by him, and the paths which he pointed out are those along which our advances must be made.

In concluding this condensed account of HERSCHEL'S scientific labors, it behoves us to remember that there was nothing due to accident in his long life. He was born with the faculties which fitted him for the gigantic labors which he undertook, and he had the firm basis of energy and principle which kept him steadily to his work.

As a practical astronomer he remains without an equal. In profound philosophy he has few superiors. By a kindly chance he can be claimed as the citizen of no one country. In very truth his is one of the few names which belong to the whole world.

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[In chronological order.]

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[Solution of a prize question. *See* this book, page 46.]
Ladies' Diary, 1779.

Astronomical observations on the periodical star in *Collo Ceti*.
Phil. Trans., 1780, p. 338.

Astronomical observations relating to the mountains of the moon.
Phil. Trans., 1780, p. 507.

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Phil. Trans., 1781, p. 115.

Account of a comet. [Dated 13th March, 1781. This was *Uranus.*]
Phil. Trans., 1781, p. 492.

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Phil. Trans., 1782, p. 82.

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Phil. Trans., 1782, p. 112 : translation in *Bode's Jahrbuch*, 1786, p. 187.

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Phil. Trans., 1782, p. 163.

A paper to obviate some doubts concerning the great magnifying powers used.
Phil. Trans., 1782, p. 173.

A letter from WILLIAM HERSCHEL, Esq., F.R.S., to Sir JOSEPH BANKS, *Bart.*, P.R.S.
Phil. Trans., 1783, p. 1.

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[This is a letter forwarding HERSCHEL'S memoir on the Parallax of the Fixed Stars, etc.]
Bode's Jahrbuch, 1786, p. 258.

On the diameter and magnitude of the *Georgium Sidus*, with a description of the dark and lucid disk and periphery micrometers.
Phil. Trans., 1783, p. 4.

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Phil. Trans., 1783, p. 247.
Bode's Jahrbuch, 1787, p. 194, p. 224.

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Phil. Trans., 1784, p. 437.

[*Bode's Jahrbuch*, 1788, p. 246, has a summary of this paper by Baron VON ZACH. See, also, *Bode's Jahrbuch*, 1794, p. 213.]

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Phil. Trans., 1789, p. 212.
Bode's Jahrbuch, 1793, p. 104.
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Phil. Trans., 1790, p. 1.
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Phil. Trans., 1796, p. 452.
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Memoir and Correspondence of CAROLINE HERSCHEL. With portraits. London, 1876. 12mo.

Herschel (W.)
[Solution of a prize question. *See* this book, page 46.]
Ladies' Diary, 1779.

Herschel (W.)
The favorite Eccho Catch . . . and the preceding Glee [by S. LEACH]. To which is added the . . . Catch Sung by Three Old Women . . . in the Pantomime called "The Genius of Nonsense" [by H. HARINGTON].

London, 1780 (?). Obl. folio. [A MS. copy of this was kindly furnished me by Dr. R. GARNETT, of the British Museum.]

Herschel (W.)

Göttingen Magazin der Wissenschaften und Literatur (1783), vol. iii., p. 4. LICHTENBERG and FORSTER, Editors.

[Letter from HERSCHEL, giving a brief account of his life. *See* this book, page 3.]

Herschel (W.)

I. *Manuscripts in possession of the Royal Society.*

1. A series of register sheets in which are entered up *all* the observations of *each* nebula, copied *verbatim* from the sweeps. 2. A similar set of register sheets for MESSIER'S nebulæ. 3. A general index of the 2,508 nebulæ of W. HERSCHEL; given the class and number, to find the general number. 4. An index list; given the general number, to find the class and number. 5. A more complete list like 4. 6. A manuscript catalogue of all the nebulæ and clusters, reduced to 1,800, and arranged in zones of 1° in polar distance; by Miss CAROLINA HERSCHEL. 7. The original sweeps with the 20-foot reflector at Slough, in three small 4to and four folio vols. of MS.

II. *Manuscripts in possession of the Royal Astronomical Society.*

This library contains "the whole series of autograph observations of each double star [observed by HERSCHEL], brought together on separate sheets by Sir WILLIAM HERSCHEL and Miss CAROLINA HERSCHEL."

[Herschel (W.)]

Some Account of the Life and Writings of WILLIAM HERSCHEL, Esq. [With a Portrait.]

The *European Magazine and London Review* for January, 1785. 8vo.

[Herschel (W.)]
Edinburgh Review, vol. i., p. 426.

[A review of HERSCHEL'S memoir, "Observations on the two lately discovered bodies," from *Phil. Trans.*, 1802. *See* this book, page 96.]

[Herschel (W.)]
"Sir WILLIAM HERSCHEL, from a London paper."

[This is a short obituary notice "furnished by a gentleman well acquainted with Sir WILLIAM and his family, and its accuracy may be relied on."]

Niles' Register, vol. 23, p. 154, Nov. 9, 1822. 8vo.

[Herschel (W.)]
Obituary: Sir WILLIAM HERSCHEL, Knt., LL.D., F.R.S.

The Gentleman's Magazine and Historical Chronicle, vol. xcii., 1822, p. 274. 8vo.

[Herschel (W.)]
Annual Register, 1822, p. 289. 8vo.

[Herschel (W.)]
W. HERSCHEL'S Sämmtliche Schriften. Erster Band. Ueber den Bau des Himmels. Mit 10 Kupfertafeln. [Edited by J. W. PFAFF. A second edition was published in 1850.] Dresden and Leipzig, 1828. 8vo.

[Herschel (W.)]
New York Mirror, vol. vi., 1829-30, p. 388.

[Herschel (W.)]
Living Age, vol. ii., p. 125 (1844). 8vo.
[Reprinted from *Chambers' Journal.*]

[Herschel (W.)]
Foreign Quarterly Review, vol. 31, p. 438. 8vo.

[Review of ARAGO'S "Analyse de la vie et des travaux de Sir WILLIAM HERSCHEL."]

[Herschel (W.)]
ARAGO'S Life of HERSCHEL.

Eclectic Museum, vol. ii., p. 556. [Reprinted from the *Foreign Quarterly Review*, vol. 31.]

Holden (E. S.)

On the Inner Satellites of *Uranus*. [Reduction of Sir WILLIAM HERSCHEL'S observations.]

Proceedings Amer. Assn. Adv. Science, August, 1874, p. 49. 8vo.

Holden (E. S.)

Index Catalogue of Books and Memoirs relative to nebulæ, clusters, etc. *Smithsonian Miscellaneous Collections*, No. 311, pp. 19–38. [Abstracts of Sir WILLIAM HERSCHEL'S memoirs (on nebulæ) in the *Philosophical Transactions*.]

Washington, 1877. 8vo.

Holden (E. S.) and C. S. Hastings.

A Subject-index and a Synopsis of the scientific writings of Sir WILLIAM HERSCHEL. [Reprinted from the *Report* of the Smithsonian Institution (1879).]

Washington, 1881. 8vo.

Krafft (J. G. F.)

Kurze Nachricht von dem berühmten Astronomen HERSCHEL und einigen seiner Entdeckungen.

Bayreuth, 1787. 8vo.

Peirce (C. S.)

Photometric Researches. [A reduction of HERSCHEL'S observations on the comparative brightness of the stars.] *Annals Harvard College Observatory*, vol. ix.

Leipzig, 1878. 4to.

Sommer (G. M.)

WILLIAM HERSCHEL . . . ueber den Bau des Himmels; drei abhandlungen aus dem englischen uebersetzt, nebst einem authentischen Auszug aus KANTS allgemeiner Naturgeschichte und Theorie des Himmels.

Koenigsberg, 1791. 8vo.

Struve (W.)

Études d'astronomie stellaire. Sur la voie lactée et sur la distance des étoiles fixes. [P. 24 *et seq.* contains an elaborate review of the construction of the heavens according to HERSCHEL.] St. Petersburg, 1847. 8vo.

Wolf (R.)

WILLIAM HERSCHEL. Zurich, 1867. 8vo.

Zach (F. von.)

Dr. WILLIAM HERSCHEL [translated from *Public Characters* and printed in ZACH'S *Monatlich Correspondenz*, 1802, part i., p. 70 *et seq.*]

III.—LIST OF THE PUBLISHED PORTRAITS OF WILLIAM HERSCHEL.

Artist, MME. DUPIERY. *Engraver*, THÖNERT. 8vo. Early portrait. Some copies in red. Profile.

Artist, F. REHBURG. *Engraver*, F. W. BOLLINGER. 8vo. Late portrait.

Artist, ——? *Engraver*, C. WESTERMAYR. 8vo. Medallion.

Artist, C. BRAND. *Engraver*, ——? 8vo. Lithograph.

Artist, ——? *Engraver*, J. SEWELL. 8vo. Profile, 1785.

Artist, ——? *Engraver*, ——? 8vo. Profile.

Artist, F. BONNEVILLE. *Engraver*, F. BONNEVILLE. 8vo. Profile.

Artist, J. RUSSELL, R.A. *Engraver*, E. SCRIVEN. 8vo. Engraved from a crayon in the possession of his son, and published by the S. D. U. K. in the *Gallery of Portraits*, vol. 5.

Artist, ——? *Engraver*, ——? 8vo. *European Magazine*, Jan., 1785. This is a bust in profile, showing the left side of the face.

Artist, ——? *Engraver*, THOMSON. 8vo. Published by Caxton, 1823. This must have been engraved before 1816, since the legend is WILLIAM HERSCHEL, LL.D., F.R.S.

Artist, Lady GORDON. From the painting by ABBOTT in the National Portrait Gallery. *Engraver*, JOSEPH BROWN. 8vo. Published in memoir of CAROLINE HERSCHEL. This is of the date 1788, or thereabouts. *See* frontispiece.

Artist, ——— ? *Engraver*, C. MÜLLER. 4to. Medallion, 1785 (?).

Artist, ——— ? *Engraver*, H. PINHAS. 4to. Legend in Russian.

Artist, BAISCH. *Engraver*, ——— ? 4to. Lithograph.

Artist, H. GRÉVEDON. *Engraver*, ——— ? Fol. Lithograph.

Artist, ——— ? *Engraver*, F. MÜLLER. Fol.

Artist, ABBOTT. *Engraver*, RYDER. Fol. 1788.

Artist, J. BOILLY. *Engraver*, ——— ? Fol. 1822. Lithograph.

Artist, ——— ? *Engraver*, J. GODBY. Fol.

R. W. S. LUTWIDGE, Esq., F.R.A.S., has an original seal with a head of Sir WILLIAM HERSCHEL, which is shown on the title-page of this work. A cut of it has been courteously furnished me by JOHN BROWNING, Esq., F.R.A.S., etc.

In 1787 a bust of HERSCHEL was made by LOCKIE for Sir WILLIAM WATSON.

A picture of HERSCHEL was painted by Mr. ARTAUD about the beginning of 1819. A portrait of HERSCHEL by ABBOTT is in the National Portrait Gallery, London. There are no doubt many other paintings in England, though I can find notices of these only. The Royal Society of London has nearly a hundred portraits of its most distinguished members, but owns none of Sir WILLIAM HERSCHEL.

INDEX OF NAMES.

N.B.—This index is intended to refer to the proper names occurring in the body of the work only, and not to the Bibliography.

THE END.